DOCTORAL PROGRAMME

Information Management

Specialization in Geographical Information System

GIS Applications on the Essential Public Services in Mozambique

ANTÓNIO DOS ANJOS LUIS

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NOVA Information Management School
Universidade Nova de Lisboa

Professor Doutor Pedro da Costa Brito Cabral, Supervisor

Abstract

Water supply and health are considered essential public services and are therefore a fundamental right for human development. The use of GIS in public services has had a tremendous growth as result of the availability of various information technology services and software, and is currently being considered useful to the understanding and treatment of health problems in different geographic areas and and optimize the locations of infrastructure and public services.

The aim of this study is to measure the geographic accessibility of population to existing healthcare centers, and find the most suitable locations for small dams/water reservoirs in the Tete province region, Mozambique, which has a pronounced water deficit. The objectives were achieved using the GIS approach, where accessibility to health services was first measured using travel time and driving scenarios to the health centers.

On the other hand, to find the most suitable locations for small dams / reservoirs a multi-criteria evaluation (MCE) analysis through an Analytic Hierarchical Process (AHP) were implemented, including local experts 'consultation. The study consider 9 criteria including slope, elevation, rainfall, stream density, lineaments, soil, land-use, distance to roads and distance to villages as the most important criteria in locating a dam.Findings from this study highlight accessibility problems, especially in the walking scenario, in which 90.2% of Mozambique was considered an underserved area. In this scenario, Maputo City (69.8%) is the province with the greatest coverage of HC. On the other hand, Tete (93.4%), Cabo Delgado (93%) and Gaza (92.8%) are the provinces with the most underserved areas. The driving scenario was less problematic, with about 66.9 % of Mozambique being considered a served area.

For dam/reservoir site location study, the results show three main categories of suitability: "Not suitable" (15% of total area), "Modestly suitable" (78%), and "Suitable" (7%). We found that 92% abandoned small dams/reservoirs were in areas classified as "Modestly suitable" confirming the robustness of our model. We also found that most of the dams/reservoirs currently operating (78%) and planned (73%) are in modestly suitable areas. This finding suggests that the decision to construct dams/reservoirs may not have considered the most critical suitability factors identified in this study. The mapped outputs may have policy implications and could be used for future decision-making processes and analysis for both the health and water resources management

Keywords: Essential public services, Accessibility, Health centers, Water scarcity, Dams/reservoir, Multi-criteria evaluation, Geographic information systems, Mozambique.

Publications

List of publication resulting from this dissertation

Articles authored

Title: *Geographic accessibility to primary healthcare centers in Mozambique.*
Journal: International *Journal for equity in* health. This is Q1 in Scimago.

Link: **https://doi.org/10.1186/s12939-016-0455-0**

Title: *Small dams/reservoirs site location analysis in a semi-arid region of Mozambique.*

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Link: **https://doi.org/10.1016/j.iswcr.2021.02.002**

Other articles co-authored

Title: *Assessing Mozambique's exposure to coastal climate hazards and erosion*.

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Link: **https://doi.org/10.1016/j.ijdrr.2017.04.002**

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Finally, I would like to express my gratitude to my parents, my wife and my children. Without their tremendous understanding and encouragement in the past few years, it would be impossible for me to complete this study.

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Chapter 1: Introduction

As an essential element of the social state, the quality of life of people, especially the most disadvantaged, requires that the universal provision of certain basic services are guaranteed (FFMS, 2021). The issue of public service is closely linked to the state model adopted at a given historical moment, to the objectives proposed by the State, its organization and modes of action and attributions of the Public Administration (Alves, 2014).

The primary function of local governments in social sate is the production and distribution of goods and essential public services and allocation of resources for such purposes (Ilal & Weimer, 2018). Essential public services are defined as a necessary services and functions ensured, regulated or controlled by governments that contributes directly to livelihood, health and dignity, aiming to improve social equity and poverty reduction (Barcarollo, 2013; USAID, 2009). As they are essential, public services must be directed towards the collective benefit of society, as their purpose is to supply the collective needs.

Beyond fundamental for the reduction of the poverty, the services must be universally affordable and accessible in order to achieve the Millennium Development Goals (Kessler & Alexander, 2004). It must be provided in a continuous and uninterrupted manner according to the principles of effectiveness, continuity, security, regularity, timeliness, generality, reasonable pricing and courtesy. Services as healthcare, provision of clean water, basic sanitation, maintenance of communication infrastructure, utilities and other, are the example of essentials public services (USAID, 2009).

Access to clean water and healthcare are considered basic rights and are fundamental to human development. Health and water are everyone's right and it is the duty of the State to provide it properly (Pessoa, 2016). It contributes to the improvement of people's lives and creates conditions that favor economic development and the general functioning of the territories. However, in many developing countries, physical access to these services remains a major problem (Ofori-Mensah, 2017). To address these issues, two research papers were developed: (i) *Geographic accessibility to primary healthcare centers in Mozambique; and* (ii) *Small dams/reservoirs site location analysis in a semi-arid region of Mozambique.*

The physical location of the healthcare unit and the travel time influences the use of health services (Weiss et al., 2020). The distance that patients must travel in order to obtain treatment has long been recognized as the main determinant of the use of health services, especially in rural environments in third world countries, where the density of health facilities is low and where the majority of people moves on foot (Buor, 2003). Many people in the developing world lose their lives due to the long distances they have to travel before reaching their nearest health center (Soai, 2012). Timely access to health care is important inasmuch as it might enable patients and physicians to prevent illness, control acute episodes, or manage chronic conditions, any of which could avoid exacerbation or complication of health conditions.

The issue of distance and time as barriers to healthcare services has not been well documented in Mozambique, where distance has been examined as a binary variable (far/close) and there are no accessibility maps showing how far or close the communities are to the health facilities. This study seeks to fill this knowledge gap by measuring geographical accessibility to health facilities in Mozambique.

On the other hand, the issue of water and the solution to its scarcity in semi-arid are dealt with in the second paper.

Through Resolution 64/292, the United Nations recognized the right to clean water and sanitation as a human right ,so the states in particular for countries developing countries and international associations were called to provide financial resources, training and transfer of technology, in order to increase efforts to provide clean, accessible and affordable water and sanitation for all (Costa, 2011; Hutton, 2016; Shaheed et al., 2014).The Therefore, Sustainable Development Goal (SDGS) 6.1 requires and recommend a full and safe coverage of safe drinking water by 2030 (Omarova et al., 2019).Water is crucial for the achievement of human rights, reducing poverty and inequality and enabling peace, justice and sustainability.

As a result of increasing stress on water resources, population growth, unsustainable consumption patterns and uncontrolled use and increased frequency of drought events over recent years, it is estimated that in 2025 one third of the world's population will have to deal with water scarcity (Lin et al., 2020; Mukheibir, 2010).

Water scarcity is a critical issue in many developing countries (Ibrahim et al., 2019). Water scarcity in this case refers to the scarcity of availability due to physical scarcity, or scarcity of access due to the failure of institutions to guarantee regular supply or due to the lack of adequate infrastructure (UN, 2021). The need to have a continuous and stable water supply for human activities implies building dams and/or reservoirs to store water during the rainy season and use it in the drought season (Sayl et al., 2016).

The construction of dams/reservoirs may provide water supplies for human needs and livestock, small-scale irrigation, and may play an important factor in improving the livelihoods of rural populations (Senzanje et al., 2008; World Bank, 2007). Small dams/reservoirs have the advantage of being operationally efficient, flexible, close to potential users, and require relatively fewer issues for management (Keller et al., 2000).

In general, the process of selecting the location for the installation of dams/reservoirs is carried out through empirical knowledge and/or according to political interests (Al-Ruzouq et al., 2019). An imprecise assessment of the dam/reservoir site and below recommended standards can have harmful effects in the long run and result in incalculable negative impacts on the environment and livelihoods of the local population (Behera, 2013).

The combination of Geographic Information Systems (GIS) and Remote Sensing (RS) enables time savings and containment of financial expenses by providing reliable and up-to-date information for water resource management (Mugo & Odera, 2019). These techniques play a fundamental role in identifying potential sites for water storage infrastructure combined with hydrological analysis and modeling (Ahmad & Verma, 2018); this study is aimed to identify the most suitable dam/reservoir sites for the semi-arid zone of the Tete.

1.1. Hypotheses

The research is based on the following hypotheses:

- The majority of Mozambicans lives on underserved areas of health centers;
- The levels of accessibility to health centers vary depending on the means of travel;
- The levels of accessibility to health centers are diametrically opposed to those of developed countries and similar to African developing countries;
- Although a semi-arid area, some areas in Tete province must be suitable for the construction of dams/reservoirs; and
- Most existing and abandoned reservoirs coincide with areas of low suitability.

1.2. Objectives

The general objective of this thesis is to carry out spatial analysis of essential public services in Mozambique.

The specific objectives are the following:

1. Measure the geographic accessibility to the Healthcare Centers in Mozambique; and
2. Identify the most suitable dam/reservoir sites for the semi-arid zone of the Tete Province, Mozambique

1.3. Methodology

The summary of methodological procedures in this study are illustrated in figure 1 and described above.

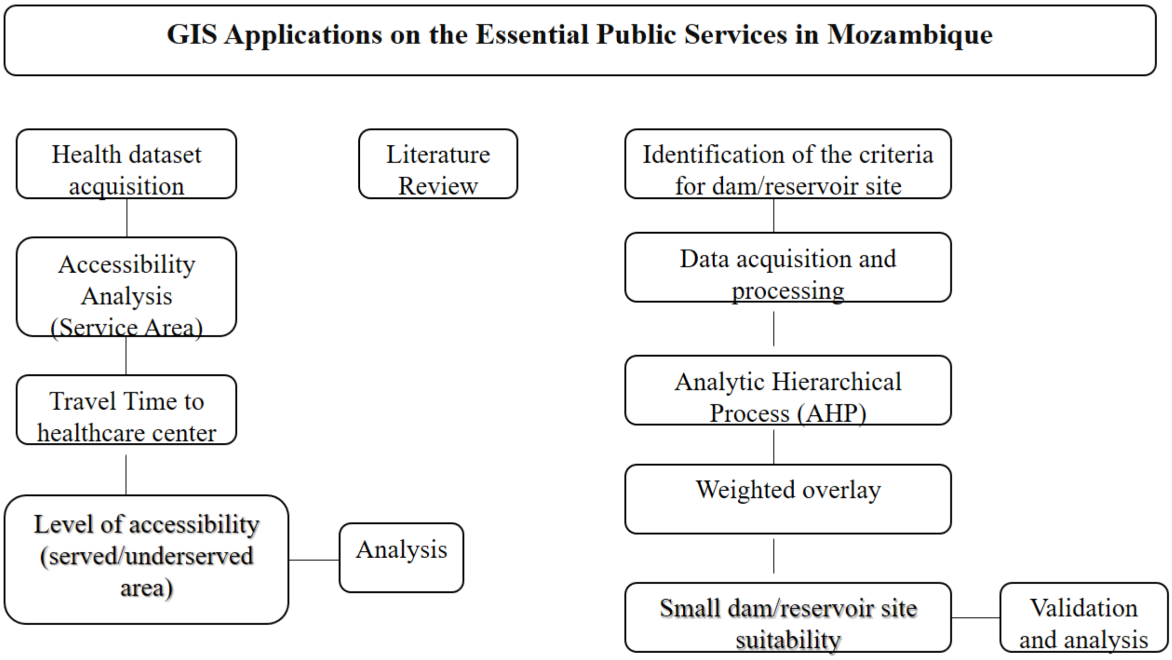

Figure 1- Methodological Flow chart

1.3.1. Literature review

The literature review was conducted to identify the state-of-the-art of geographic accessibility methods to health centers, and the identification of the criteria for dams/reservoir site location case studies. This was very useful to identify the gaps in the field, fine-tune the research objectives and methodology design.

The research was carried out based on scientific articles published in international journals because it is commonly valued, recommended and more easily accessed (Gomes, 2006). In order not to limit the sources to only scientific articles, the author also resorted to thesis and dissertations, in a moderate way, relevant research presented and published in conference proceedings and other very important scientific meetings, as well as some books, recognized as important accessed on the Z-Library platform[1].

As inclusion criteria, priority was given to articles published in the 2013-2020, in English and Portuguese language. However, for the development of this research, some studies prior to 2013 were taken into account, whenever the information was considered relevant for its discussion and interest. On the other hand, documents published in PPT, publications without dates, editorials and letters to the reader were excluded.

1.3.2. Data processing and analysis

1.3.2.1. Data collection

The main datasets were obtained from relevant institutions which deals with health care and water management, namely National Directorate of Health and ARA Zambezi. Other spatial data were obtained online in specific webpage duly referenced.

1.3.2.2. Geographic health care accessibility measure

The accessibility model was carried out through service area tool of Network Analyst extension from ArcGIS, using two scenarios of travel time: driving time and walking time.

[1] https://z-lib.org/

1.3.2.3. Small dam/reservoir site suitability

To come up with a small dam/reservoir site suitability a Geographical Information System (GIS) based approach was used to implement a multi-criteria evaluation (MCE) analysis through an Analytic Hierarchical Process (AHP), including local experts ‘consultation.

1.4. Thesis organization

This thesis comprises of 4 chapters. The first chapter is introduction of the study. It starts with the contextualization of essential public services, with special emphasis on accessibility to health services and strategies for mitigating water scarcity in semi-arid areas through small dams / water reserves construction. This chapter also contemplates the problem statement, the hypotheses, the objectives, the methodological framework, the expected contribution and ends up with the structure of the thesis. Chapter 2 and 3 refers to the published papers by the author, and chapter 4 is the chapter of the study which entails the conclusions drawn from the research results in chapter 2 and 3. Recommendations and prospects for the future are also part of this chapter. The research papers published in the scope of this thesis are the following:

- The first paper studied the geographic accessibility to primary healthcare centers in Mozambique. This paper is Q1 in Scimago and was published in International *Journal for equity in* health (doi: 10.1186/s12939-016-0455-0)
- The second paper studied and found the most suitable locations for small dams/reservoirs in semi-arid region of Mozambique. This paper is Q1 in Scimago and was published in the International Soil and Water Conservation Research (https://doi.org/10.1016/j.iswcr.2021.02.002)

Chapter 2: Geographic Accessibility to Primary Healthcare Centers in Mozambique

António dos Anjos Luis[1] and Pedro Cabral[2]

[1] Universidade Católica de Moçambique, Beira, Moçambique, email: aluis@ucm.ac.mz, Corresponding author

[2] NOVA IMS, Universidade Nova de Lisboa, 1070-312 Lisboa, Portugal, email: pcabral@novaims.unl.pt

2.1. Background

Universal health coverage has been considered a pillar of sustainable development and global security (United Nations, 2012). Thus, health related facilities should be universally available, accessible, acceptable, appropriate, and of good quality (AAAQ framework) (Campbell et al., 2013). In public health there is a direct link between the distance patients travel to access health and the reduction of ill health and suffering in a country (Australian Institute of Health and Welfare, 2011). Patients tend to use health facilities more if they are located close to them than if they are far way (Mizen et al., 2015). The issue of distance of the patients to the centers is seen as one of the main determinants of use of health services (Buor, 2003). In third world countries the distance covered by patients is usually greater than in developed world countries, in which healthcare facilities are more accessible. This has an important impact on the quality of life of these countries (Buor, 2003). Accessibility to healthcare is the capability of a population to obtain a specified set of healthcare services (Islam & Aktar, 2011). Reflecting the equilibrium between characteristics and expectations of the providers and the clients, quality care has been conceptualized in four dimensions of access (Levesque et al., 2013): (1) geographic accessibility– the physical distance or travel time to the potential user; (2) availability – having the adequate type of care for who is needing it; (3) financial accessibility – willingness and ability of users to pay for services; (4) acceptability – response of the health services providers to the social and cultural individual expectations and communities in general.

Identifying different levels of spatial accessibility to healthcare services in a certain area allows decision makers to understand the impacts of opening, closing, changing location or modifying the services offered by existing facilities (Delamater et al., 2012).

Currently, several advanced methodological approaches are used to estimate health accessibility, such as gravity, kernel density, and catchment area models (Langford & Higgs, 2006). However, the conventional and most common techniques used to calculate accessibility in public health research are still the Euclidean and network distance (Mizen et al., 2015). Euclidean distance techniques describe a location's relationship to a source or a set of sources based on the straight-line distance (Environmental Systems Research Institute, 2016). Networked distance is the physical travel path or road to reach the destination (Kadobera et al., 2012). The constraint of the Euclidian distance is that it does not take into account physical barriers to movements and transportation routes, thereby underestimating the real travel distance (Boscoe, 2013; Gatrell, 2009). Because of the sparse road network and natural obstacles, such as water and mountains, it is not adequate to estimate accessibility using Euclidian distances (Dahlgren, 2008). On the contrary, when road networks are used, the accessibility tends to be greater in places where there are many good road networks in combination with the presence of health facilities (Mwasi, 2010).

The World Health Organization (WHO) suggests the use of travel time, instead of distance, to assess healthcare services because this method takes into consideration the conditions of the roads and the means of transport (Munoz & Källestål, 2012). There is no universally accepted range of time for allowing people to travel for medical care. Some authors consider the range of 30 minutes for access to patient care as reduced (Rooväli & Kiivet, 2006). Others state that people living at more than 45 minutes from healthcare facilities are more likely to be marginalized; and there is a group of authors that consider one hour as an adequate (which agrees with the opinion of ambulance drivers (Egresi, 2013)).

The use of GIS in public health has had a tremendous growth as result of the availability of various information technology services and software, and is currently being considered useful to the understanding and treatment of health problems in different geographic areas (Fradelos et al., 2014). A considerable number of studies concerned with measures of access to healthcare services were developed as a result of the availability of GIS in health organizations and the increasing availability of spatial disaggregate data (Higgs, 2004).

Mozambique is located in the Southern Region of Africa, and has borders with Tanzania (North), Malawi, Zambia and Zimbabwe (West), and South Africa and Swaziland (South). The country has an area of 799,380 km^2, with a long eastern shoreline on the Indian Ocean (Figure 2). The total estimated population for 2012 is 23.4 million, spread over 11 provinces, including Maputo City, which has provincial status (WHO, n.d.). Mozambique ranks 180th position out of 188 countries in the Human Development Index 2015, being classified as a low development country (United Nation Development Programme (UNDP), 2015). Over 70 percent of the population lives in rural areas and below the poverty line. Although agriculture is the main source of household food and income, the production at the household level is often insufficient to maintain food security (World Vision, 2013). The country's high poverty levels, the chronic malnutrition in a context of marked food insecurity, the low levels of education of women, the poor access to clean water and poor sanitation, and the limited access to quality health services are the main determinants of health status and burden of disease in Mozambique (Saúde, 2013). The epidemiological situation of Mozambique is largely pre-transitional, i.e. dominated by communicable diseases, namely malaria, HIV/AIDS, diarrhea, acute respiratory infections and tuberculosis, but with a pronounced rise of non-communicable diseases (cardiovascular diseases, injuries, cancers, etc.), particularly in urban areas (WHO, n.d.).

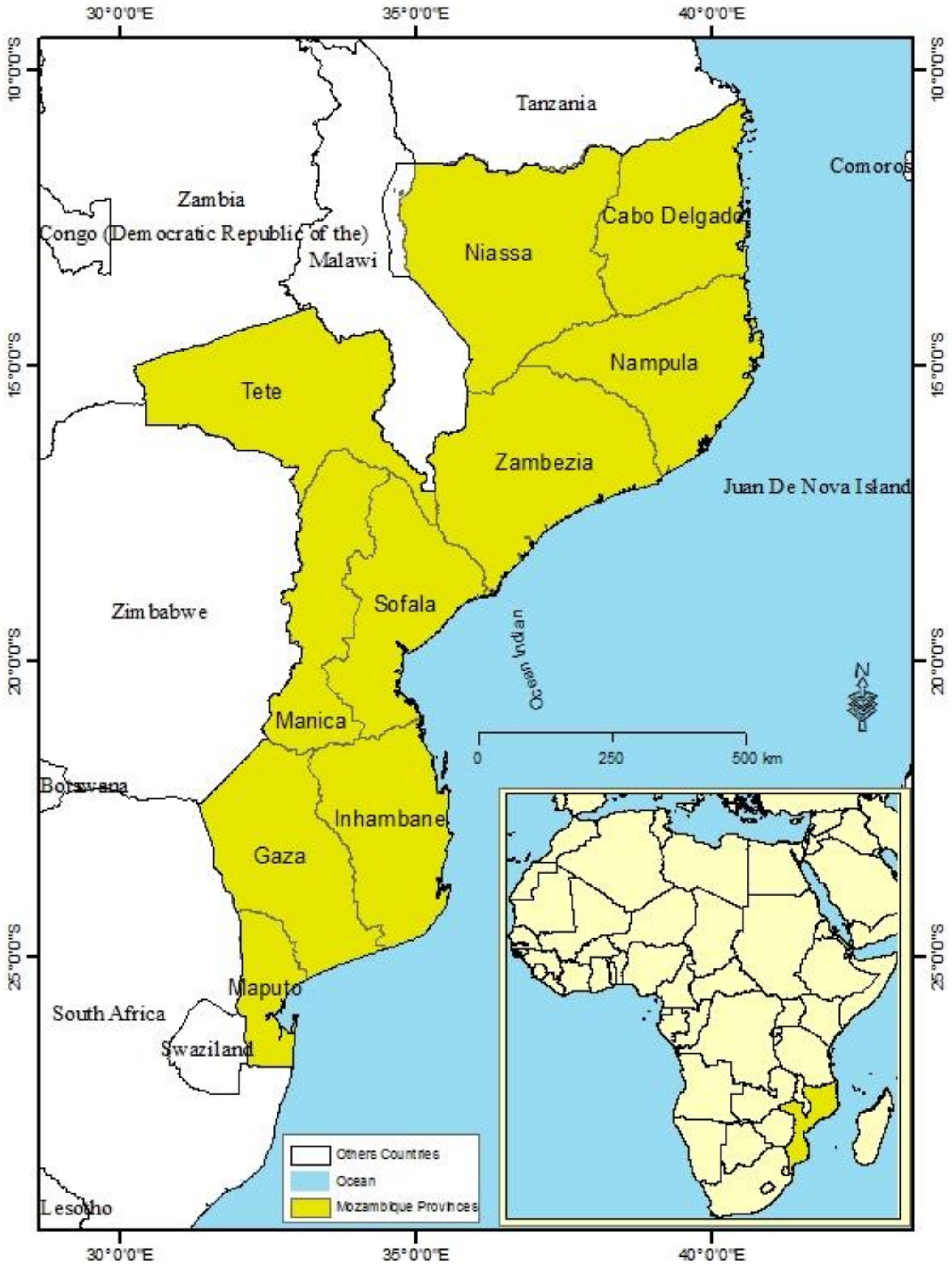

Figure 2-Geographic location of Mozambique

Strengthening health systems and ensuring increasing equitable access to health services, and building management capacity in the public health sector as well as expanding its coverage are top strategic priorities for the country (World Health Organization, 2014). The health system in Mozambique is organized in four levels, namely (World Health Organization, n.d.): a) the primary level, comprising urban and rural HC; b) the secondary level, comprising general, rural, and district hospitals; c) the tertiary level, comprising the hospitals of the provincial capitals; and d) the quaternary level, represented by the central hospitals of Beira, Nampula, and Maputo and the Specialized Hospitals. The primary level of the system encompasses a set of basic actions to solve the most common problems in the community. Between 70-80 % of the problems that drive the demand for healthcare can be solved at this level.

The focus of this paper is the primary level of healthcare facilities. The secondary level is more differentiated and developed, supporting the primary level technical and organizational problems. This level solves more complex situations than the primary level, referring to other levels of care (tertiary and even quaternary) the solution of situations that go beyond the scope of its competence. The secondary level hospitals have as secondary function to dispense healthcare and constitutes the first level of referral for patients who cannot find solution to their health problems in health centers of their areas of influence. Provincial hospitals provide tertiary healthcare and are the reference level for patients who cannot find a solutions for their health problems in district, rural, and general hospitals, as well as for patients from HC located in the vicinity of the provincial hospital, which has neither a rural hospital nor general hospital to which they can be referred . The quaternary level has a regional and national basis, and is in charge of the three existing central hospitals in the cities of Maputo, Beira, and Nampula. Each of these central hospitals is responsible for one national territory and for the psychiatric hospitals of Infulene and Nampula.

It is hypothesized that a lack of health facilities close to people is a major obstacle to reaching health facilities and can inhibit access (Graham et al., 2010). Long travel times and greater distances can lead patients not to repeat the visit to the healthcare facilities (T.T.Awoyemi et al., 2011).

The issue of distance and time as barriers to healthcare services has not been well documented in Mozambique; usually, distance has been examined as a binary variable (far/close) and there are no accessibility maps showing how far or close the communities are to the health facilities. Additionally, there has been no systematic attempt to analyze the effects of the distance barriers to healthcare in Mozambique. This study seeks to fill this knowledge gap by measuring geographical accessibility to HC facilities in Mozambique. We calculate the spatial coverage of the existing primary HC facility network using two scenarios of travel time: driving and walking. We also estimate the number of people within and outside 60 minutes from an HC to understand the degree of accessibility of the Mozambican population to the health network.

2.2. Methods

The focus of this study is primary HC because these units encompass a set of basic actions to solve the most common problems in the community. The location of HC was obtained using the USAID dataset survey of year 2000. This dataset was updated to year 2016 by the authors of this study through a list provided by the Minister of Health of Mozambique. The total number of HC included in the analysis is 1,061, corresponding to 81.2% percent of all existing HC in Mozambique. The Gridded Population of the World (GPW) data from the Global Rural-Urban Mapping Project (GRUMP) projected for 2015 was used to map the population of Mozambique. These data were downloaded from the Internet (CIESIN, 2005) and consist of an estimation of human population by 2.5 arc-minute grid cells. The digital elevation model (DEM) for Mozambique was obtained from the Aster GDEM (*ASTER GDEM*, 2011) with 30m of spatial resolution. A total of 101 tiles were mosaicked in order to obtain a single DEM file for the whole country. The elevation data were used to calculate walking time with QGIS free open source software (*QGIS Geographic Information System.Open Source Geospatial Foundation Project*, 2015). For the study area delimitation we used an administrative map produced by the National Cartography and Tele-detection Centre from Mozambique (CENACARTA, 1997).

This dataset represents the administrative division of the country in three levels: provincial, district and administrative post. The road network was also obtained from the same source and was classified in three categories: main road, secondary road, and tertiary road (mostly unpaved). The mapping of road network and modeling of spatial data can be used to identify restrictions on vehicle movement (Ferreira & memoriam), 2013). After correcting the topological road network problems, this dataset was superposed with the health facilities. During this process we verified that some health facilities were too far from the road network, which could confound the analysis. To minimize this problem we updated the road network by digitizing some road segments from Google Earth (Google, 2013). These were then exported to ArcGIS software (ESRI, 2012). The villages and communities dataset was obtained from USAID project data of year 2000.

The accessibility analysis was carried out using the Service Area (SA) tool of Network Analyst extension from ArcGIS (ESRI, 2012). Two scenarios of travel time for Mozambique were created: travel time by roads and by walking. The SA was based on the driving distance by road and walking distance criteria described in Table 1. The straight-line Euclidean distance to create a buffer around the HC was initially considered as a solution to create the SA. However, this approach was not realistic from a walkability standpoint because it fails to take into account physical barriers, such as water bodies, railway lines, buildings, and other obstructions (Rattan et al., 2012). The function used to calculate driving and walking time in minutes through the road network was:

Length of the Roads / Maximum Speed (for each type of the road) *60

For determining the geographical accessibility to HC, two scenarios for travelling to the health facilities were considered (Table 1): driving time and walking time. The estimates for walking time were obtained with QGIS python plugin which uses Tobler's hiking formula to determine the travel time along a line depending on the slope (Neto, 2015). The input data were the vector layer with lines (road network) and the DEM. The fields with estimated time in minutes in forward and reverse directions were created with the default value of speed of 5 km/h. As a result of the lack of infrastructures and motorized transport services the predominant way of transport in rural Africa areas is walking (Munoz & Källestål, 2012). Research in less developed countries, often uses walking time or travel time by public transportation to measure distance to the nearest hospital (Egresi, 2013).

Table 1- Walking and driving travel times on different road types in Mozambique

	Travel Time	
Road Type	Walking	Vehicle
Primary	5 km/h (12 min/km)	80 km/h (0.75 min/km)
Secondary	4 km/h (15 min/km)	50 km/h (1.2 min/km)
Tertiary	4 km/h (15 min/km)	20 km/h (3.0 min/km)

The maximum travelling time to be considered a served area was set to 60 minutes. Areas more than 60 minutes away from HC were considered underserved for both scenarios. The population should have access to a health facility within one hour of walking (Munoz & Källestål, 2012). More than that, people will pay a high cost (financially and emotionally) to visit a healthcare center (Egresi, 2013). The number of villages and population were superposed with the category's distance in order to know the villages and population served for each section of time. The number of population for each province was estimated for the two scenarios for the served and underserved areas.

2.3. Results

For the driving scenario, the calculated catchment areas of each HC were divided in to eight categories: 30, 45, 60, 120, 250, 500, 1000, and 1500 minutes. The number and location of the villages served by each catchment area were obtained (Figures 3 and 4).

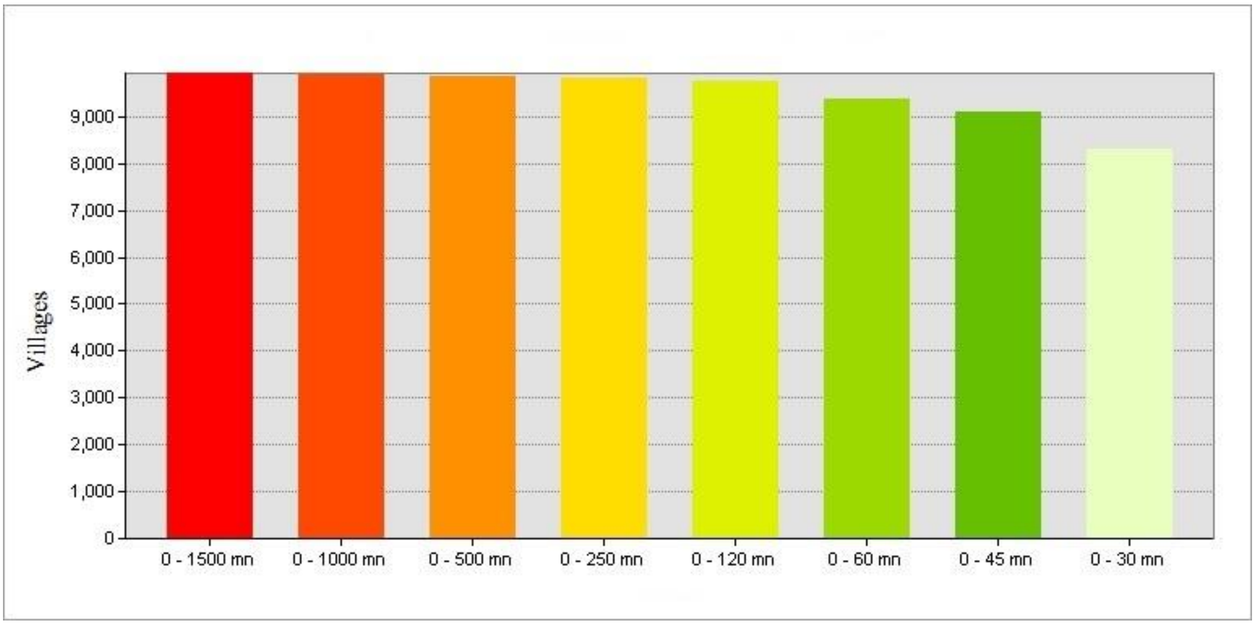

Figure 3-Number of villages per driving time category

The map in Figure 3 shows that the best areas served by the health network are located mainly in the provinces of Nampula, part of the province of Zambezia, Tete, central and Northern provinces of Manica and Sofala as well as the south of Gaza, and most of the Maputo Province. In contrast, the driving travel time to HC is lowest in the provinces of Niassa, Cabo Delgado, and part of Gaza province.

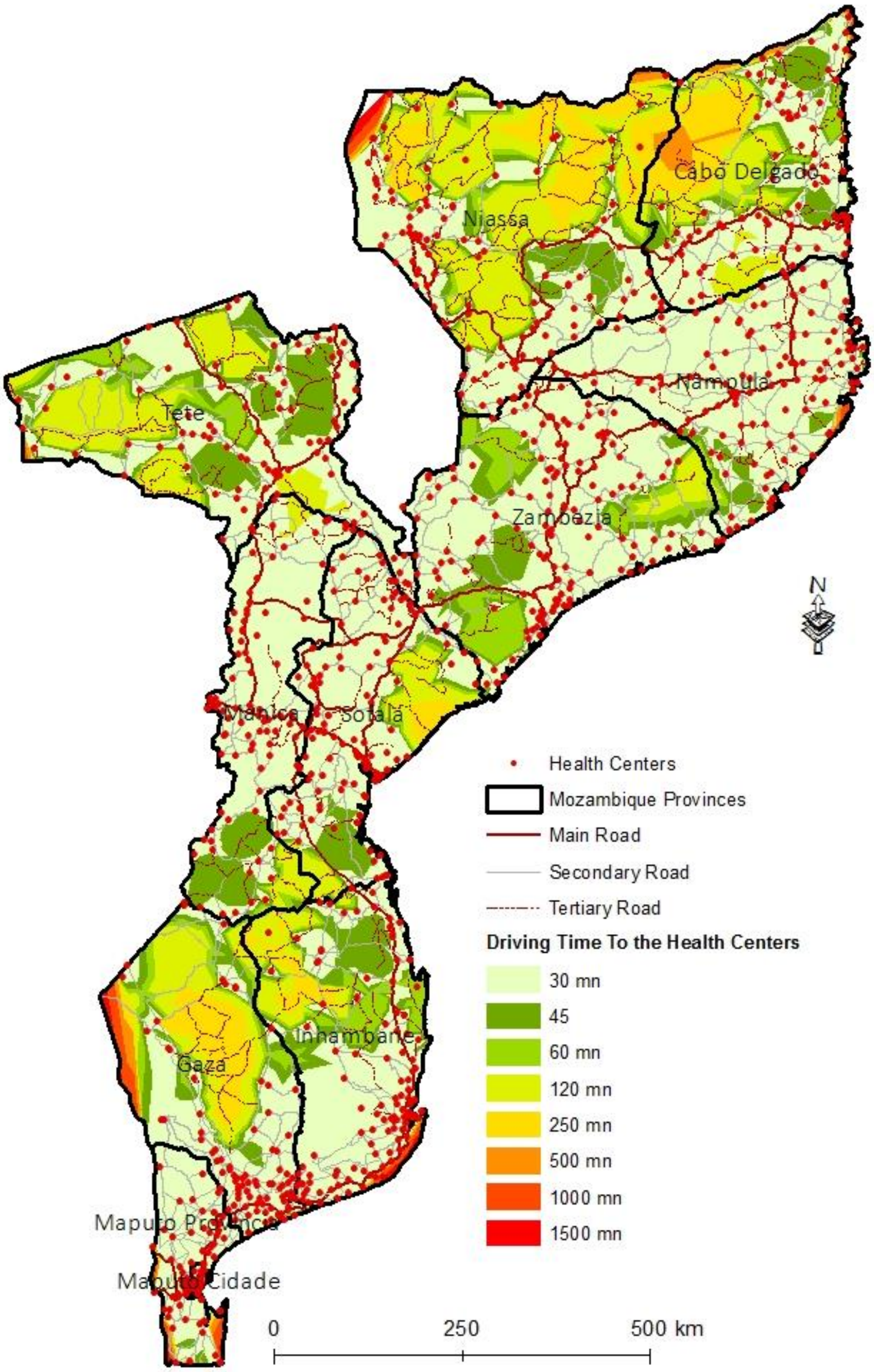

Figure 4-Driving time to Healthcare Centers in different time categories

The reclassification of the distances to identify the areas served and underserved by HC revealed two classes of distances: served area (0-60 min) and underserved area (more than 60 min) (Figure 5).

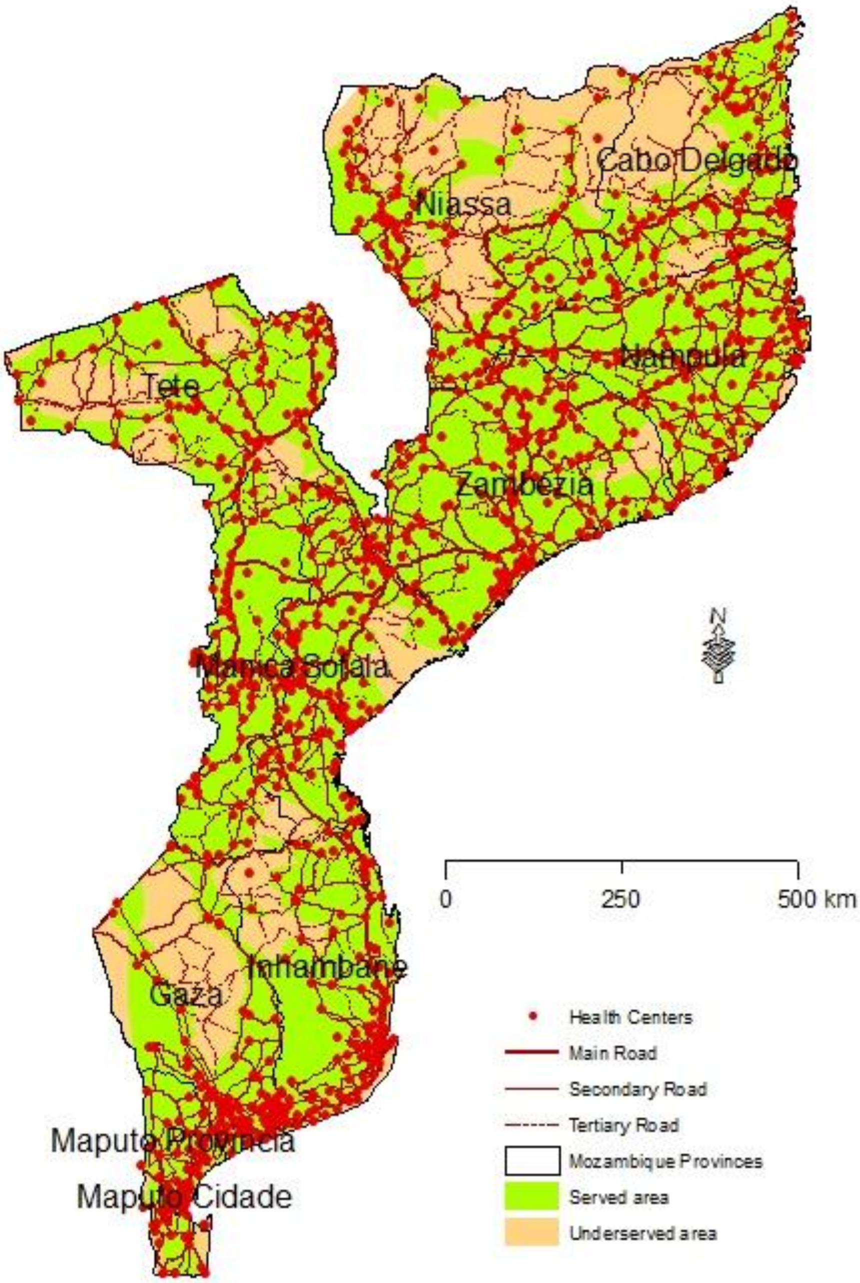

Figure 5-Served and underserved area of Mozambique by Healthcare Centers by driving

Superposing the areas obtained in the previous map with the projected population data for year 2015 allowed us to obtain the number of population by province: 20,106,550 (93.8%) people living in the well served area, and 1,345,088 (6.2%) living in the underserved area. Nampula, Zambezia, Tete, and Manica are the provinces with the highest number of population in the served areas (Figure 6). Cabo Delgado, Niassa, and Tete are the provinces with the highest number of underserved population, which contrasts with Maputo Cidade, and Province with very low values of people in this condition. Tete is (paradoxically) in both "served" and underserved" areas.

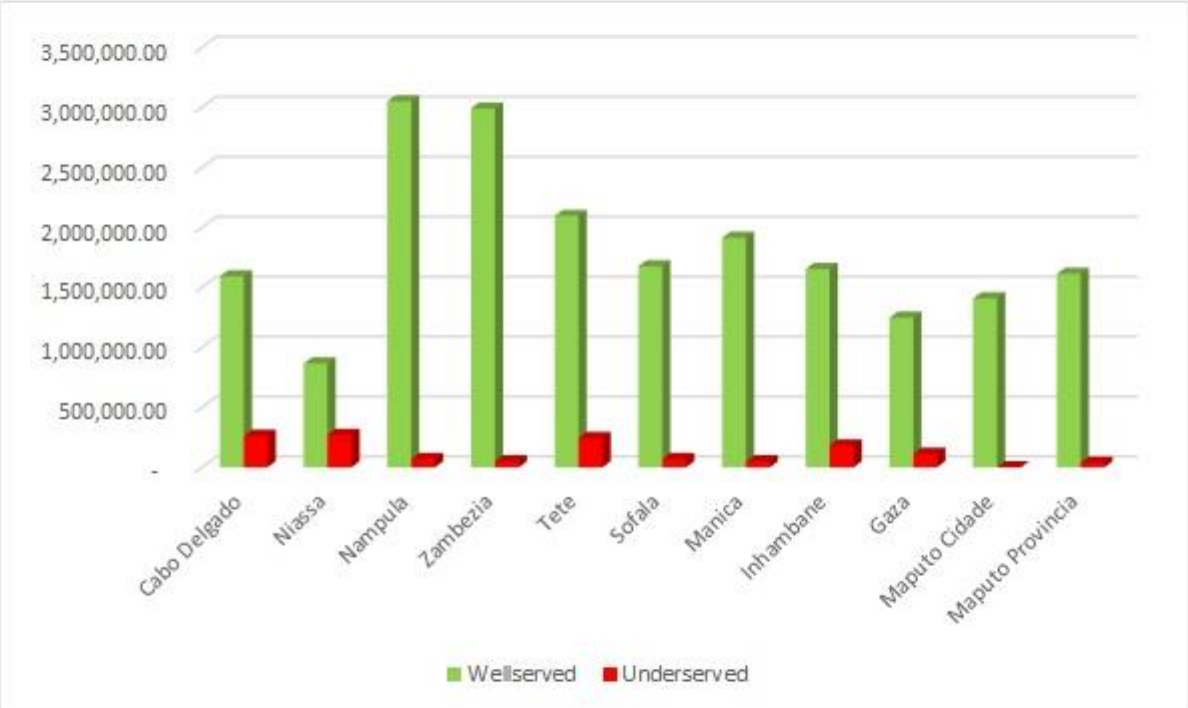

Figure 6-Population Number on the served and underserved areas by HC in the driving scenario

For the walking scenario, and using the same time breaks as in the previous scenario, we found that there are 1,460 villages located within the distance of 30mn, representing 3% of the total number of villages (Figure 6). This number increases slightly to 2,023 within 45mn to the HC, i.e. 4.1 % of the total. Most of the population can reach an HC only if they walk more than 60 minutes (87.5%). Figure 8 shows the SA for walking time in Mozambique.

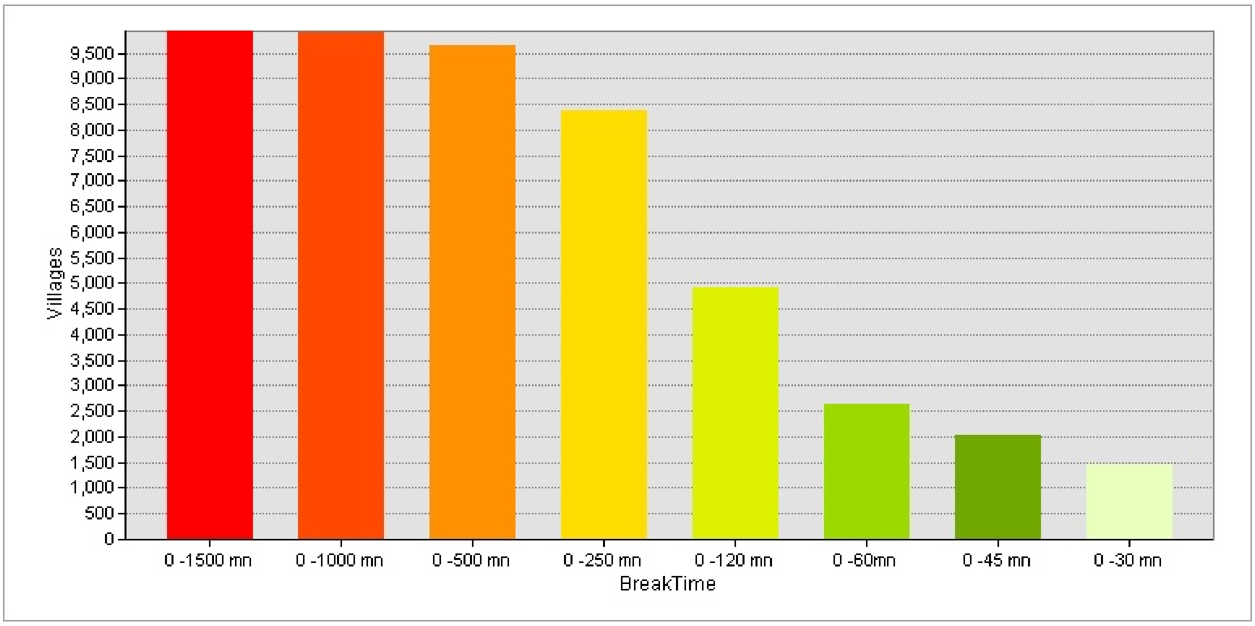

Figure 7-Number of villages per walking time category

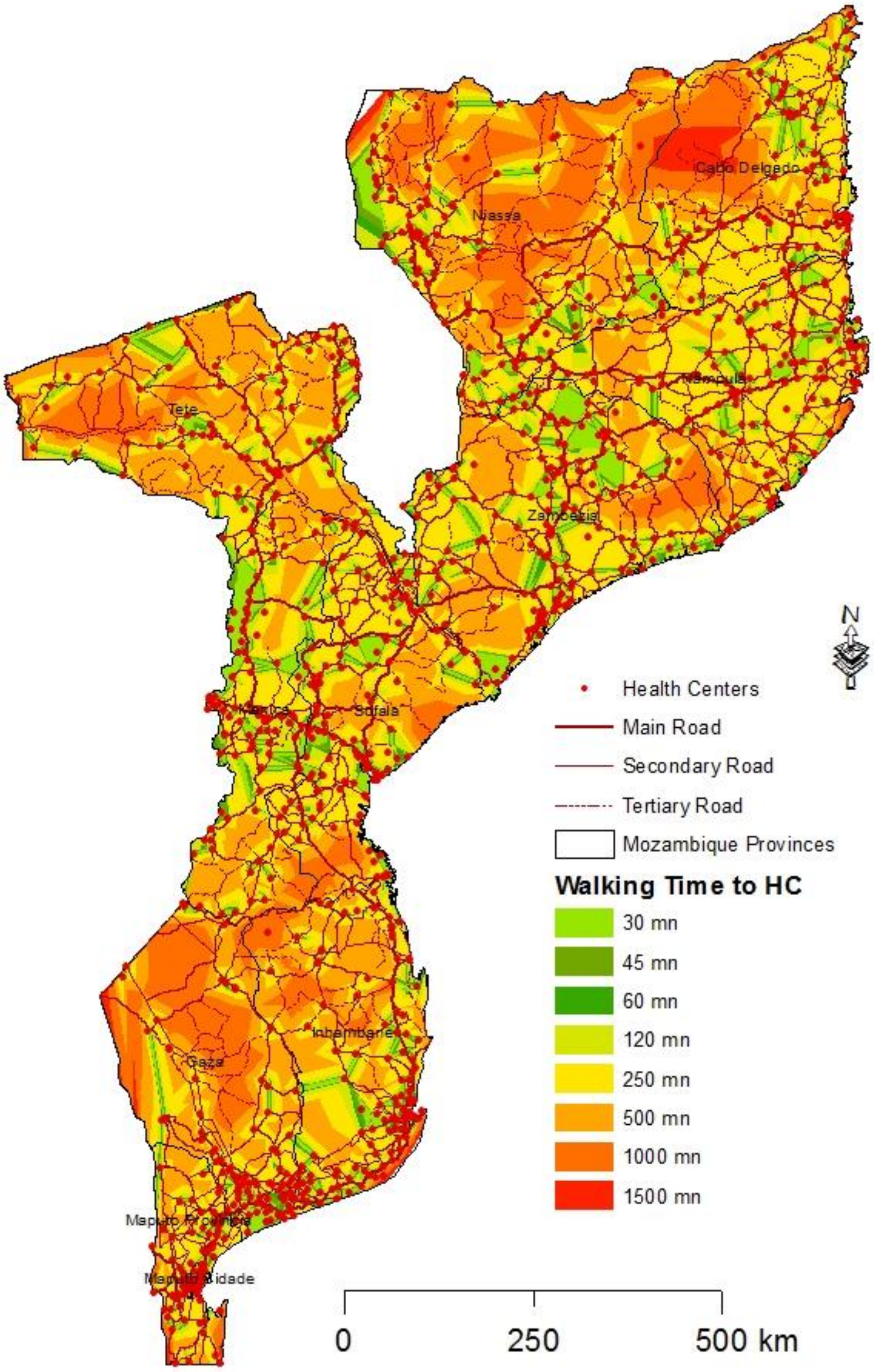

Figure 8-Walking time to Healthcare Centers in different time categories

An analysis to determine the number of villages per province in each time category was also carried out (Figure 9). The provinces of Nampula (north), Zambezia and Tete (center), and Inhambane (south) have the highest number of villages outside 60 minutes from an HC.

Maputo, Maputo city, and Sofala are the provinces with the lowest number of villages located outside 60 minutes from an HC.

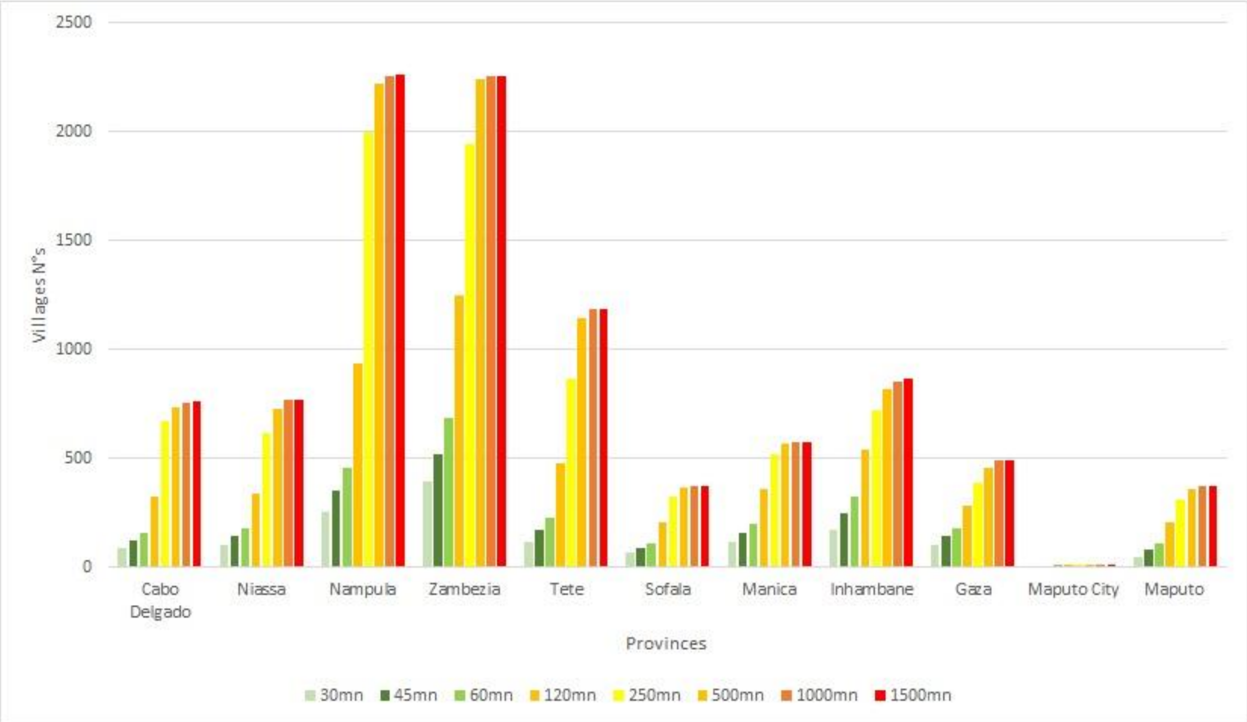

Figure 9-Number of villages per province and walking time categories

The reclassification of the distances to identify served and underserved areas by HC revealed two classes: well served areas (0-60 min) and underserved areas (more than 60 min) (Figure 10).

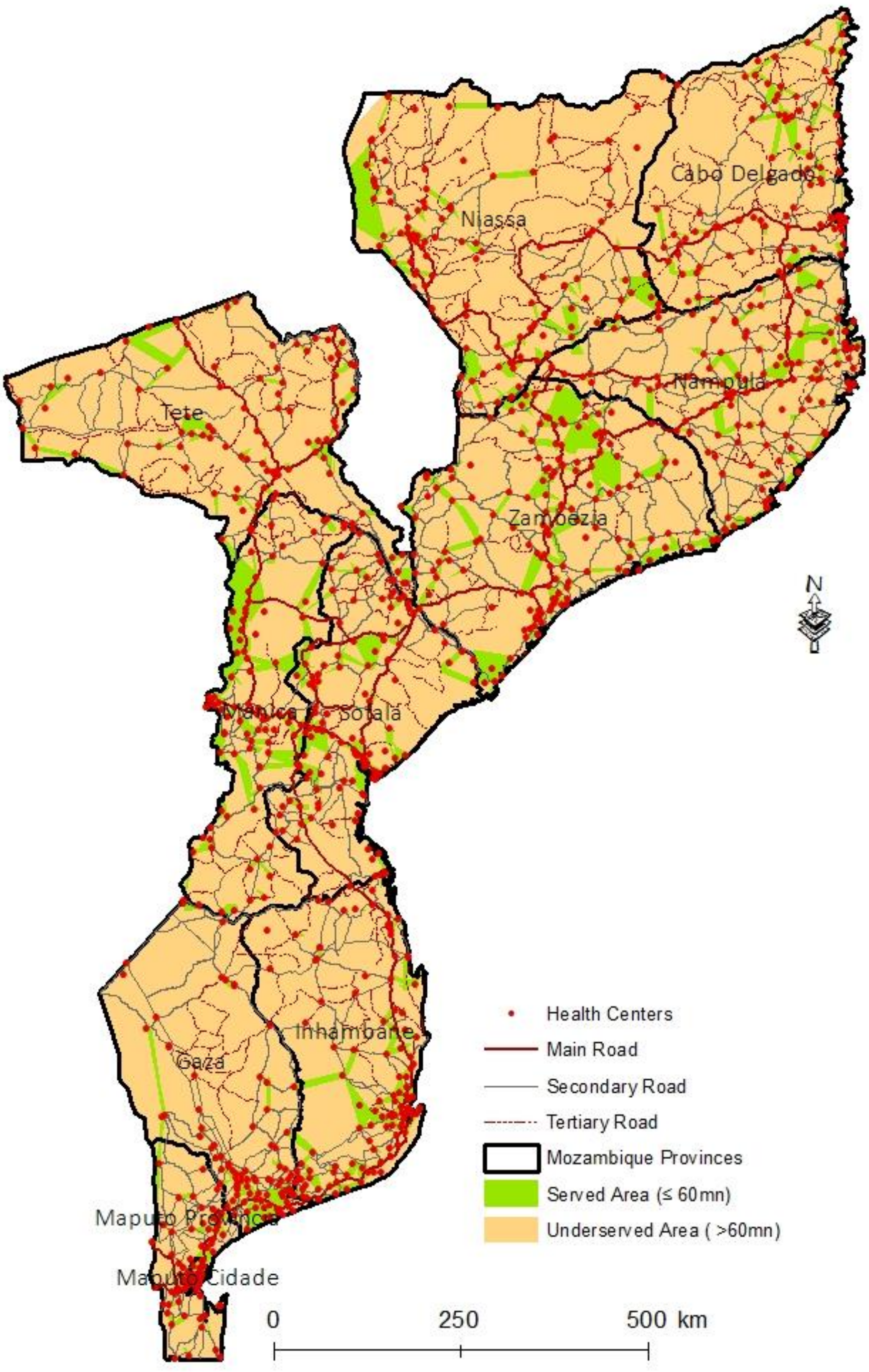

Figure 10- Served and underserved area of Mozambique by Healthcare Centers by walking

About 7,151,066 (33.3%) of Mozambicans are living in a served area, while the remaining population, 14,300,572 (66.7%) are living in an underserved area. Maputo, Zambezia, and Maputo City are the provinces with the highest number of people in the area considered well served regarding the walking time to HC (Figure 11). Nampula, Zambezia, and Tete are the provinces with the highest number of underserved people, contrary to Maputo, Maputo City, and Gaza with very low values of people in this condition.

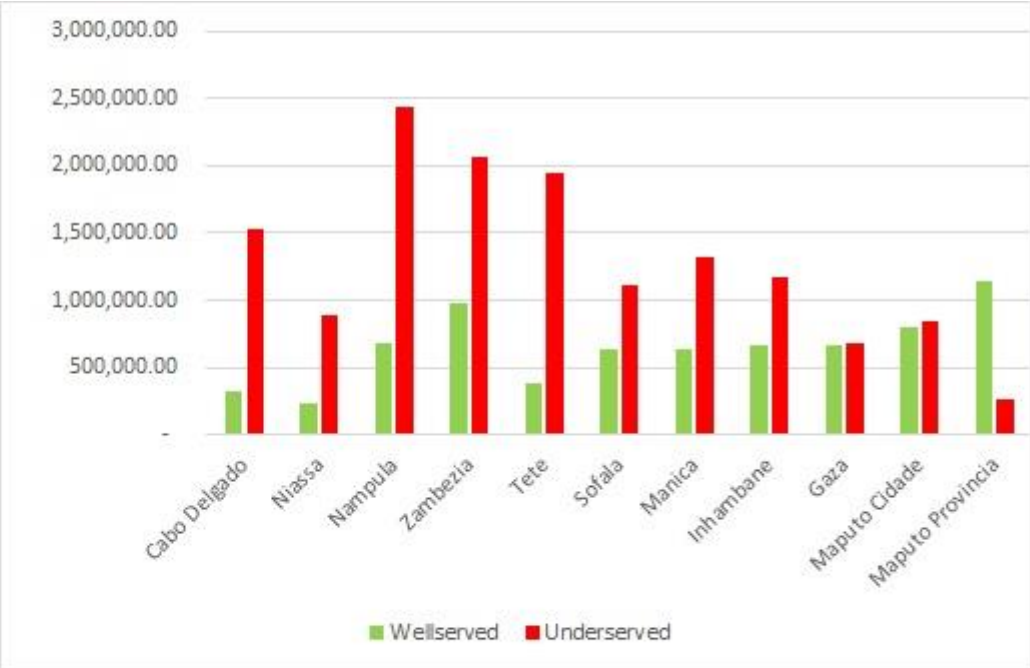

Figure 11-Population in served and underserved areas by Healthcare Centers in the walking scenario

2.4. Discussion

This study identifies critical areas in Mozambique where HC may need to be relocated using realistic travel time estimates of driving and walking. In the line of several studies stating that the population should have access to a health facility within one hour of walking, our analysis also uses 60 minutes as the maximum travelling time (Blanford et al., 2012). In both scenarios, the areas that can be accessed in more than one hour were classified as underserved area. The findings from this study highlight problems, especially in the walking scenario, in which 90.2%

of Mozambique was considered an underserved area. For the driving scenario, about 66.9 % of Mozambique was considered a served area. Maputo City (100%), Maputo (90.7%), and Zambezia (82%) are the provinces with greatest coverage of HC network. Niassa (62.1%), Gaza (52.9%), and Cabo Delgado (48.3%) are the most underserved provinces. Niassa and Gaza are the two provinces with a negative value for the difference between served and underserved area, i.e., the underserved area is greater than the served area. This can be explained by the reduced number of roads and their poor condition. For the walking scenario, only 9.8 % of Mozambique was considered a served area. Maputo City (69.8%), Manica (15.8%), and Zambezia (15.4%) are the provinces with greatest coverage of HC network. Tete (93.4%), Cabo Delgado (93%), and Gaza (92.8%) provinces are the provinces most underserved. This, as in the driving scenario, can also be related to the reduced number of roads and their poor condition. Only Gaza province has a positive value of the difference between served and underserved area, i.e. the underserved area is smaller than the served area.

Regarding the population distribution (Table 2), we found that the problem of accessibility is mainly in the walking scenario; about 66.7% of the Mozambican area is located in an underserved area. The accessibility problem is less important than in the scenario of driving (6.27%). However, there are not many people using their own vehicles or public transportation, especially in the rural areas of the country, where there is a lack of infrastructures and motorized transport services.

Table 2- Summary of the population distribution in the two scenarios

	Scenario 1-Driving		Scenario 2-Walking	
	Population		Population	
	N◦	%	N◦	%
Population Served (≤ 60 mn)	20,106,550.88	**93.73**	7,151,066.40	33.3
Underserved Population (> 60 mn)	1,345,087.65	6.27	14,300,571.40	**66.7**
Total	21,451,638.53	100	21,451,637.80	100

The present study has important limitations. First, there is no updated national database of health facilities, although there has been an increase in the number of HC since year 2000. We georeferenced the new HC from the list of recent health facilities (without coordinates) obtained from the Minister of Health of Mozambique. This process was based on the name of the HC and the corresponding name of the villages. Thus, the new HC with names different from the village were not included (there were 245 HC in this situation, representing 18.7% of the total). We believe both these concerns conservatively biased our estimates of travel times and distances to HC. Second, we are aware that the physical access to HC is only one component of access to healthcare. Factors such as perceived quality of healthcare services, trust in the healthcare providers, quality of and sensitivity in communication by care providers with the public, and ability to pay for the services (Russell, 2005) are potentially determinants to healthcare access that are not addressed in this study. Third, although we used realistic travel time in our analysis, further adjustments may be necessary. For instance, walking speed varies depending on age and the type of individuals involved in the trip (slower for sick adults and adults carrying children compared with adults walking on their own (Blanford et al., 2012; Graham et al., 2010). Therefore, it would be useful to consider these elements for calculating travel times in future studies. In addition, it would be important to incorporate travel cost to identify areas where costs act as obstacles for the health accessibility (Mclaren et al., 2013).

Despite these limitations, the present study has several strengths. We estimated travel times and distances using road networks, avoiding straight-line distances. Road travel time estimations produce more accurate results than straight-line distance models because people are inclined to use road networks rather than travel in a straight line (Brabyn & Skelly, 2002). We used geographic locations for each HC as opposed to the approximate locations at district level. We also used population data which is not assigned to the administrative level, avoiding the problems of using aggregated data. Finally, we reported results at national and province levels allowing for the identification of regional disparities.

We have also made some assumptions, including that patients will always travel to the nearest HC. Notwithstanding, they may wish to use more distant care facilities thought to provide better quality services. Another assumption is that travel happens along an optimum path, but due to habits, social factors, environmental and surface conditions, or other costs, some part of the population may prefer to use other routes (Ray & Ebener, 2008).

2.5. Conclusions

This paper has measured the travel time from any point in Mozambique to its closest HC using two different scenarios and provided new insights about the accessibility to healthcare services in the country. The results of this research show that in terms of geographical accessibility, walking is the most problematic and worrying scenario because the majority of the Mozambican population need 60 minutes or more to reach an HC.

The findings from this study highlight accessibility problems that are similar to those faced by many African countries (Blanford et al., 2012; Okwaraji et al., 2012; Schoeps et al., 2011). The dissatisfaction caused by distance and long travel time to benefit from healthcare influences the way people respond to the healthcare system in most African countries (Soai, 2012). People can be frustrated and with negative perceptions of their service providers when they are facing long waiting times to access healthcare services (Soai, 2012). These results are completely opposite to those of developed countries such as France, where people can access hospital care in less than 45 minutes, and 75% in less than 25 minutes (Coldefy et al., 2011).

Our findings may have policy implications for strategies and could be used for advocacy and presentations to donor partners and government, to improve the universal access to the health coverage (United Nations, 2012). In Mozambique, improving the accessibility to health facilities could be achieved in three ways: the first involves the creation of new HC or the reallocation of some HC to maximize the accessibility; the second involves optimizing the public transport network, adapting the offer to the population needs; the third involves the construction of new roads and the rehabilitation of existing roads (the majority of roads are unpaved in rural areas). This integrated view is essential to address the inequalities that arise in the territories, making access to health services more equitable.

Chapter 3: Small dams/reservoirs site location analysis in a semi-arid region of Mozambique

António dos Anjos Luis[1] and Pedro Cabral[2]

[1] Universidade Católica de Moçambique, Beira, Moçambique, email: aluis@ucm.ac.mz, Corresponding author

[2] NOVA IMS, Universidade Nova de Lisboa, 1070-312 Lisboa, Portugal, email: pcabral@novaims.unl.pt

3.1. Introduction

Water is the basis of life and livelihoods since it supports the health of ecosystems and is the fundamental element for sustainable development (Lisa Guppy & Anderson, 2017). Its availability and storage are useful for drinking, field crop irrigation, and economic development (Raza et al., 2018). Hence, the United Nations recognized ensuring water security as a sustainable development goal (SDG) (Goal 6) (Gain et al., 2016). However, many people worldwide do not have secure access to suitable water to meet their most basic needs (Detoni & Dondoni, 2008; UNICEF-WHO, 2019) . The lack of water resources is likely to be one of the biggest human problems in the next decades (Rezaei et al., 2013; Vörösmarty et al., 2013). Climate change will significantly impact the hydrological regime, water availability, and quality by increasing the frequency and severity of droughts and floods, rainfall variability, and higher temperatures (Luhunga et al., 2017). Thus, there is a great concern that climate change could worsen the water resource crisis in areas with water scarcity (Abu-allaban et al., 2014; Malinowski & Skoczko, 2018). Projections for Africa by 2020, as a consequence of climate change, point to an increase in water stress with a reduction in agricultural incomes of 50% in some regions, severely compromising the access to food (Ammar et al., 2016).

Water scarcity is a critical issue in many developing countries (Ibrahim et al., 2019). Particularly in arid and semi-arid areas where evaporation exceeds precipitation, water scarcity affects livelihoods and food security since in the majority of the available water comes from the rain during the rainy season or the groundwater close to the land surface (Abdalla et al., 2017).

The need to have a continuous and stable water supply for human activities implies building dams and/or reservoirs to store water during the rainy season and use it in the drought season (Sayl et al., 2016). Dams are transverse barriers to the direction of the flow of a water course to accumulate or raise the level of the water body (Ghazal & Salman, 2015). A reservoir is an artificial water body usually created in a river valley due to water-retaining constructions for accumulation and storage of water (Nagy et al., 2002). The construction of dams/reservoirs may provide water supplies for human needs and livestock, small-scale irrigation, and may play an important factor in improving the livelihoods of rural populations (Senzanje et al., 2008; World Bank, 2007) . Small dams/reservoirs have the advantage of being operationally efficient, flexible, close to potential users, and require relatively fewer issues for management(Keller et al., 2000). Experiences with small and medium-size dams demonstrate that these contribute significantly to rural poverty reduction by increasing agricultural productivity and household food security, diversifying local economies and improving local incomes (World Bank, 2007).

In general, the process of selecting the location for the installation of dams/reservoirs is carried out through empirical knowledge and/or according to political interests (Al-ruzouq et al., 2019). An imprecise assessment of the dam/reservoir site and below recommended standards can have harmful effects in the long run and result in incalculable negative impacts on the environment and livelihoods of the local population (Behera, 2013). The combination of Geographic Information Systems (GIS) and Remote Sensing (RS) enables time savings and containment of financial expenses by providing reliable and up-to-date information for water resource management (Mugo & Odera, 2019). These techniques play a fundamental role in identifying potential sites for water storage infrastructure combined with hydrological analysis and modeling (Ahmad & Verma, 2018); RS technology because it allows covering large and inaccessible areas in a short time and different resolutions, providing different environmental and hydrologic parameters for the analysis, and GIS tools because it integrates all these thematic layers together (Elbeih, 2015).

GIS and RS through approaches together with multi-criteria evaluation (MCE) techniques, such as Analytic Hierarchy Process (AHP), Boolean logic, fuzzy logic, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), among others, allow the articulation and aggregation of geospatial information to perform dam site suitability mapping and analysis (Al-Ruzouq et al., 2019; Jozaghi et al., 2018; Lee et al., 2020).

The selection of modeling techniques used to analyze dam/reservoir suitability varies according to the available data, expertise and local context. When using MCE analysis, several factors that affect dam/reservoir site suitability can be considered, such as the character of foundations, topography, hydrological aspects, spillway capacity, availability of construction materials, submerged land value, accessibility and living facilities (Duggal & Soni, 2007). Al-Ruzouq, Shanableh, Yilmaz, et al., (2019) provide a comprehensive list of factors and respective techniques used in dam suitability studies in many regions of the world, such as Iraq, Pakistan, Sweden, India, and Malaysia. Many other studied locations can be found in the literature, such as the United Arab Emirates (Al-ruzouq et al., 2019), Iran (Jamali et al., 2018; Yasser et al., 2013), South Korea (Choo et al., 2017) among other locations. However, studies are rare for Mozambique's semi-arid region, which struggles significantly against water scarcity. This study fills this gap by providing the first dam/reservoir suitability mapping study for a semi-arid region in Mozambique. This aspect is crucial since one of the strategic and priority objectives of the Mozambican government is to reduce the vulnerability of rural communities to climate risks and natural disasters through the rehabilitation and construction of 80 small dams/reservoirs to support irrigation for small producers and increase production in drought agricultural areas and improve food security (AR, 2020). This paper aims to identify the most suitable dam/reservoir sites for the semi-arid zone of the Tete Province, Mozambique. Specifically, we aim to:

- Identify the biophysical and socioeconomic factors based on a literature review;
- Use an AHP with local expert opinion to create a dam/reservoir suitability map; and
- Validate the results obtained through the abandoned dam/reservoirs and provide an outlook on the current operational and planned dam/reservoir infrastructure.

Results are expected to contribute with relevant information to support the Southern African Development Community water protocol signed in Johannesburg in 2002. Within this protocol, Mozambique established a regional agreement among the countries in which an action plan for drought mitigation has been delineated, including measures to expand the access to drinking water to populations, particularly in arid and semi-arid areas, and the creation of infrastructures to increase the storage capacity and reduction of water loss (MICOA, 2005).

3.2. Study area

The study area is in the south of the Tete province, Mozambique, in the districts of Cahora Bassa, Changara, Chiuta, City of Tete, Luenha, Magoe, Maraza, Moatize and Mutarara covering an area of 48454.4 km^2, considered one of the semi-arid regions of Mozambique (Fig. 12). According to the census, there were 1,070,712 people living in these districts in 2017 (INE, 2019). The region is inhabited mainly by a rural population whose survival depends fundamentally on agriculture. Agriculture is the largest sector of the country's economy. About 80% of households are involved in the agricultural sector, contributing up to 29 % of the Gross Domestic Product (GDP)(FAO, 2016).

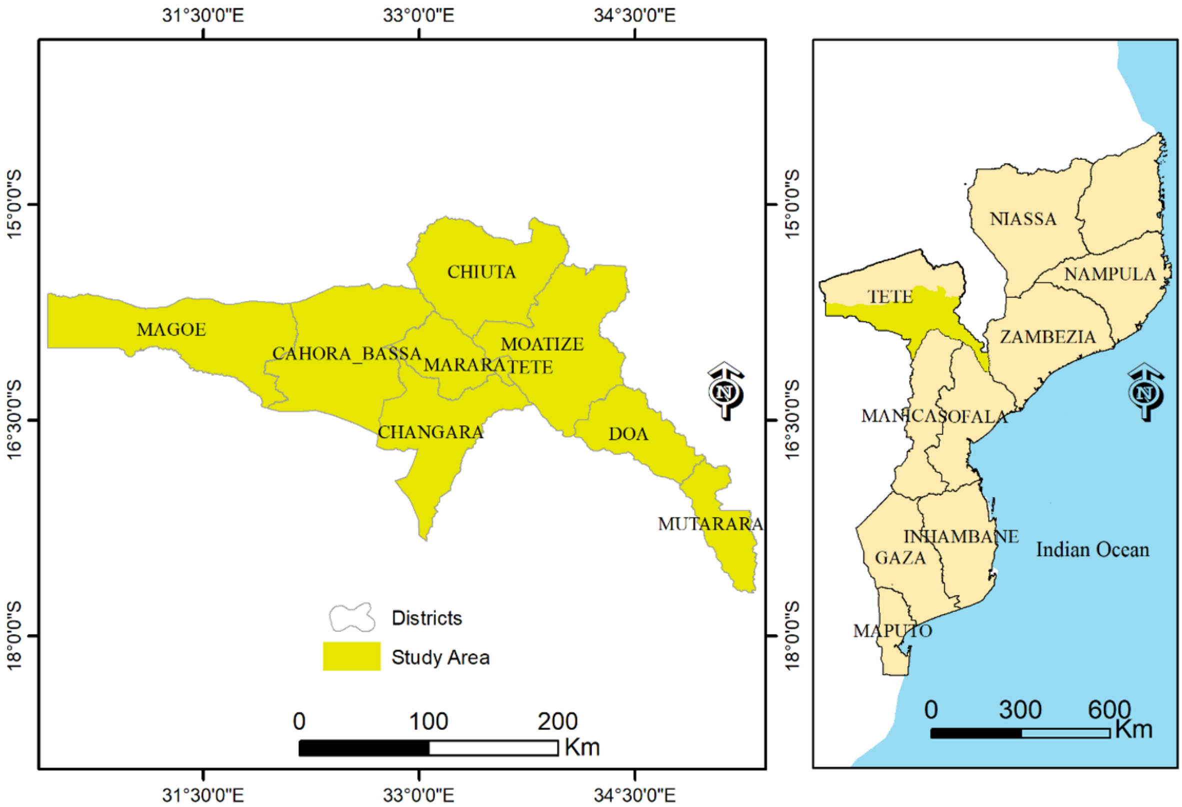

Figure 12-Geographic location of the study area

The population's agricultural practice and food security are affected by problems related to climate change problems, such as drought, floods, and cyclones (Engelman, 2009). The vulnerability of this region is partly due to irregular precipitation since the rainy season often does not start as predicted resulting in unpredictable seeding seasons (Fig 13). Rainfall events concentrate in very short periods causing soil erosion by the surface runoff (MICOA, 2005). The southern region of the Tete Province, north of Sofala and Manica and Inhambane and Gaza provinces are the most critical regions with a high-risk drought level (INGC, 2017) (Fig. 14).

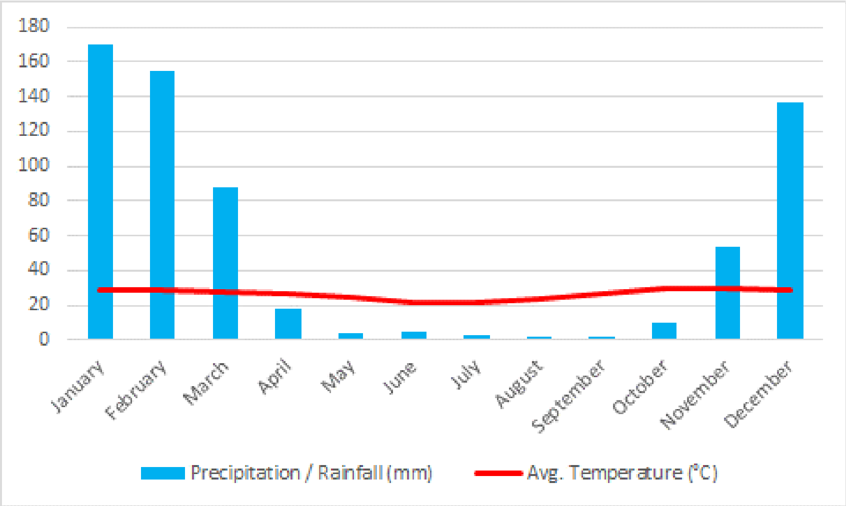

Figure 13-Tete average rainfall and precipitation

Source: https://en.climate-data.org

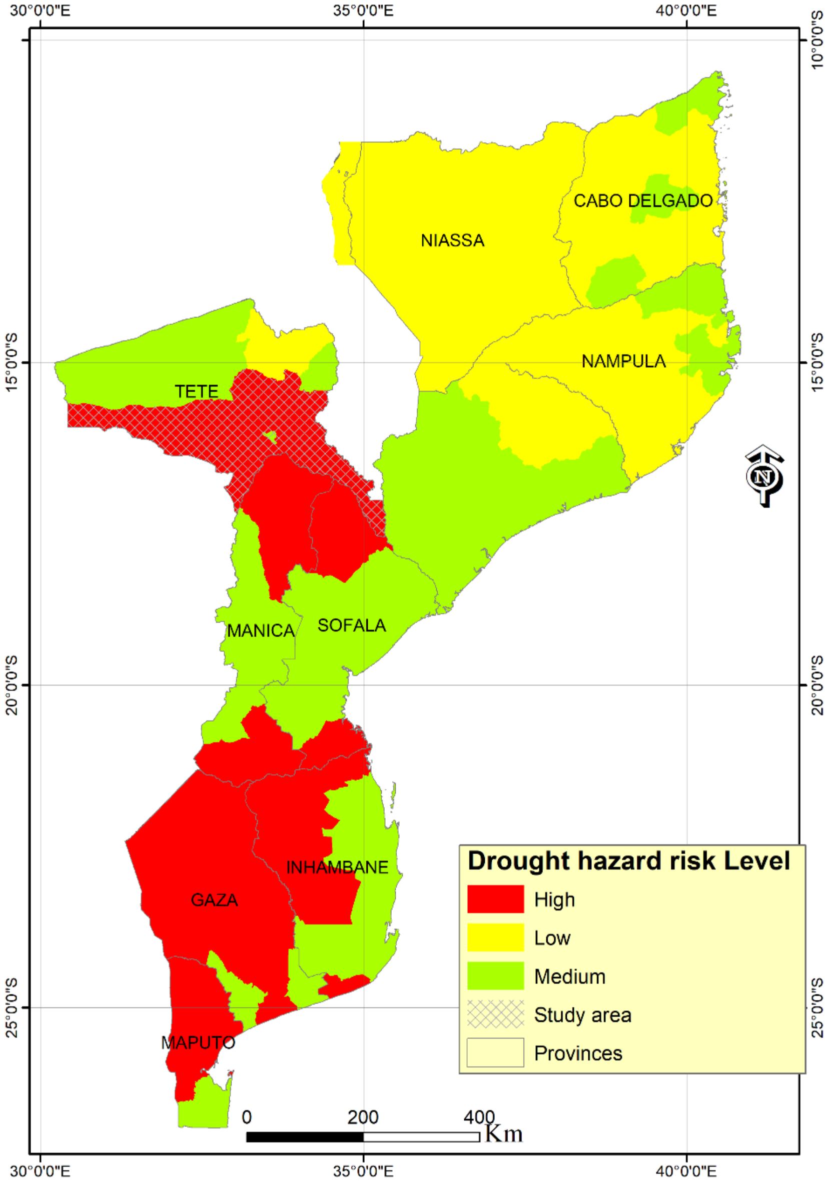

Figure 14-Mozambique drought hazard risk level (Adapted from INGC, 2017)

The lack of water in Tete's semi-arid region is related to the severity of climate and to the lack of infrastructures to store water. There is insufficient groundwater extraction through the excavation of artesian wells allied to a low quantity of dams/reservoirs with the capacity to meet population's demand. Recently, the National Institute of Disasters showed a great interest in implementing the Johannesburg agreement and intends to find better ways to increase water availability for inhabitants, crop and livestock production by creating dams/reservoirs in the best available areas. Due to the water scarcity in the region, the development of artificial water storage is necessary and mandatory for ensuring reliable water supply during periods of reduced natural water availability (droughts) as well as for retaining excessive water during periods of floods (World Bank, 2007).

3.3. Data and Methods

3.3.1. Methodological approach

Multi-Criteria Evaluation (MCE) methods provide a framework for facilitating decision making through information exchange and negotiation among stakeholders (Kiker et al., 2005; Malczewski, 2006). An approach involving several geospatial operations was adopted to determine the suitability of siting small dams/reservoirs based on multiple criteria and an Analytic Hierarchy Process (AHP) (Saaty, 1986) (Fig. 15).

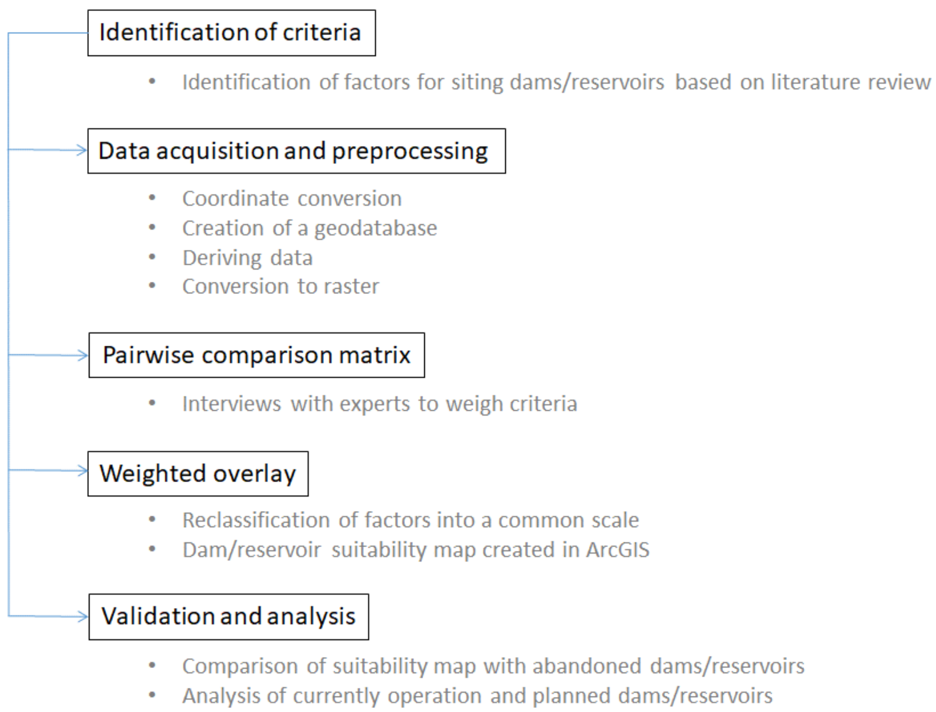

Figure 15- Flowchart of research methodology

3.3.1.1. Identification of the criteria

A literature review was carried out to determine the most relevant criteria to locate dams/reservoirs. This exercise included identifying factors, constraints, and exclusionary areas considering Tete's region specific biophysical and socioeconomic conditions and data availability (Table 3).

Table 3 Used criteria and rationale

Criteria	**Rationale**	**References**
Elevation	Elevation influences the location of dams/reservoirs since it affects the water accumulation and movement. Lower elevations are preferable to higher elevations.	(Al-Ruzouq, Shanableh, Merabtene, et al., 2019)
Slope	Higher slopes have a higher risk of landslides and put more pressure on the foundation of the infrastructures. The higher the slope in the construction site the lower the potential for storing water and sediment, meaning that lower slopes have more storage volumes.	(Ahmad & Verma, 2018)
Distance to roads	The presence of roads and settlements close to the proposed sites will reduce the costs of water transportation.	(Othman et al., 2020)
Rainfall	Is the primary source of runoff water recharge. Rainfall intensity and its distribution are some of the pre-requisites for designing a water harvesting system.	(Prinz & Singh, 2000)
Lineaments	Lineaments are linear features on the Earth's surface which reflect the geological structure such as faults or fractures. Areas near lineaments are potential weakness zones for installing infrastructures.	(Elbeih, 2015; Othman et al., 2020)
Distance to villages	The closer dams/reservoirs are to populations the lower will be the costs of water transportation.	(Mugo & Odera, 2019)
Land use land cover	Areas proposed for constructing of dams/reservoirs should be in or close to agricultural land to reduce the distances of farmers searching for water and the cost of transferring water from the reservoir to agricultural land. In addition, the primary objective of the dam/reservoir proposed for the study area is to assist crops field irrigation.	(Mugo & Odera, 2019)
Soil type	The type of soils is influenced by its texture, structure and depth which determine soil infiltration rates and the amount of runoff.	(Jha et al., 2014)
Stream density	Provides the necessary runoff water for dam/reservoir function, since different drainage network levels indicate different amounts of runoff	(Jha et al., 2014)

	water when the streams are upper stream tributaries and main downstream streams. Areas with high drainage density are ranked higher in suitability compared to areas of low drainage.	(Jha et al., 2014; Mbilinyi et al., 2014)

3.3.1.2. Data sources and preprocessing

Several spatial datasets in vector and raster formats and with different scales and resolutions were used in the study to create the factors to be included in the MCE modelling (Table 4).

Table 4 Data used and their sources

Data	**Description**	**Scale/Spatial resolution**	**Source**
Study Area	Polygon with boundary of semi-arid region of Tete Province	1:250000	(CENACARTA, 1997)
Band 6 of Landsat 8 OLI (2016)	Shortwave infrared band used for lineament extraction (Landsat scene 170/72)	30 m	(USGS, 2016)
Roads	Polylines data with existing roads		(CENACARTA, 1997)
Villages	Point data with the main settlements	1:250000	(CENACARTA, 1997)
Digital Elevation Model (DEM)	Raster dataset with elevation	30 m	ASTER GDEM (JPL & NASA/METI, 2012)

Land use/Land Cover	Polygons with land use and land cover categories (2018)	_	MITADER (MITADER, 2018)
Soil	Polygons with soil types	_	DPA-INIAM (DPA-INIA, 1995)
Rainfall	Raster dataset showing the mean of rainfall	1 km^2 Global Climate data	(Ficke & Hijmans, 2017)
Dams/reservoirs	Point data with the dams/reservoirs	_	ARA-ZAMBEZE (ARAZAMBEZE, 2020)

The study area dataset was obtained from CENACARTA (CENACARTA, 1997). The lineament structure was derived using the lineament extraction algorithm in PCI Geomatica software (PCI, 2018). Because of the ease in distinguishing between types of rocks and minerals, band 6 of the Landsat 8 satellite was used to map these geological structures (Aretouyap et al., 2020; Epuh et al., 2020). Short-wave infrared (SWIR 1) and band 6 of the Landsat 8 image for 2016 were downloaded from the EarthExplorer platform (United States Geological Survey, n.d.) using the following path and row: 167/72 (12-Aug), 168/72 (19-Aug), 168/71 (28 Aug), 169/71(26-Aug) and 170/71 (17 Aug). The distance to roads and villages were obtained using the Euclidian distance tool of ArcGIS (ESRI, 2017). A Digital Elevation Model (DEM) (NASA JPL & NASA/METI, 2012) with a resolution of 30m was obtained for the Tete Region with elevation ranging from 0 to 1545m (above sea level). The slope was derived from the DEM using the surface tool of the Spatial analyst extension of ESRI ArcGIS software (ESRI, 2017). Soil data for the study area were obtained from the National Soil map, scale 1:1000000 (DTA-INIA, 1995). The rainfall data based on the mean annual rainfall were obtained from WorldClim (Fick & Hijmans, 2017). WorldClim is a set of global climate layers (gridded data) with a spatial resolution of 1km^2. The data for this criterion were derived from the DEM using the hydrology extension of ArcGIS software (ESRI, 2017), after proceeding with the sink fill, flow direction identification, calculation of the flow accumulation and definition of the stream network. Stream density was calculated using the Spatial Analyst Density tool in ArcGIS (ESRI, 2017).

After acquiring and pre-processing all data, these were converted into raster and stored in a spatial geodatabase using a World Geodetic System (WGS) 84, Universe Transverse Mercator (UTM) coordinate system with 30m spatial resolution.

3.3.1.3. Pair-wise comparison matrix

AHP was originally developed by (T. L. Saaty, 1986) and has been applied to many fields (Choudhary & Shankar, 2012; Colak et al., 2020; Dedeoğlu & Dengiz, 2019; Martins et al., 2012). The implementation of AHP involves the creation of a comparative decision-making preference matrix and determining the factor weights (T. L. Saaty, 1986). The pairwise comparison is applied on all criteria using the fundamental scale proposed by Saaty (1986) (Table 3). In the comparison process, a scale of numbers is used indicating how many times more important one element is over another element with respect to the criterion or property to which they are compared (Saaty, 2008). This method enables a decision-making group to focus on areas of agreement and disagreement when setting criterion weights (Drobne & Lisec, 2009).

Table 5- Relative importance. Adapted from Saaty (1986)

Intensity of relative importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one criterion over another
5	Strong importance	Experience and judgment strongly favor one criterion over another
7	Very strong or demonstrated importance	A criterion is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one criterion over another is of the highest possible order of affirmation
2, 4, 6, and 8	Intermediate	Can be used if necessary

A structured interview was undertaken with four local experts with a background in geology, water resource management, hydrology, and civil engineering, respectively. The interview, carried out in January 2020, aimed at exploring their opinions regarding the relative importance of the selected criteria for dam/reservoir siting and the creation of the pairwise comparison matrix. The weighted vector of this matrix was normalized, and the normalized weight vectors were obtained according to the relative level of importance of the criteria used (T. L. Saaty, 1986). A consistency ratio (CR), which measures how consistent the judgments have been relative to large samples of purely random judgments, is computed from the resulting normalized vector values (T. L. Saaty, 1986) (Eq. 1). If the CR is over 0.1, then the judgments should be considered untrustworthy.

$$CR = CI / RI \qquad \text{(Equation 1)}$$

where CR is the consistency ratio, CI is the consistency index (Eq. 2), and RI represents a random consistency index derived from a sample of randomly generated reciprocal matrixes (R. W. Saaty, 1987; T. L. Saaty, 1986).

$$\text{CI} = (\lambda_{max} - n) \,/\, (n - 1) \qquad \text{(Equation 2)}$$

where λ_{max} is the principal Eigen value, i.e. the value obtained from the summation of products between each element of the Eigen vector and the sum of the columns of the reciprocal matrix, and n is the number of factors.

3.3.1.4. Suitability index

After determining the weights, all the criteria were reclassified into a common evaluation scale before performing the weighted overlay analysis in ESRI's ArcGIS Spatial Analyst (ESRI, 2017). Five classes of suitability were used in this process: “Highly unsuitable”; “Not suitable”; “Modestly suitable”; “Suitable” and “Highly suitable”. Highly faulted areas are not suitable for dam/reservoir construction, so dam sites should be located at least 100m away from lineaments (Othman et al., 2020). The lineaments were reclassified in two classes of suitability; less than 100m (“Highly unsuitable”) and more than 100m (“Highly suitable”). Soil classes were reclassified according to their level of suitability (DTA-INIA, 1995). All the remaining input rasters were reclassified using Natural Breaks (Jenks) classification method available in ArcGIS. This method identifies real classes within the data, creating accurate representations of trends in the data (Karlsson et al., 2017; Oswald Beiler & Treat, 2015).

In this study, we used a Weighted Linear Combination (WLC), which is based on a weighted average that can easily be understood and implemented within a GIS environment using map algebra operations and cartographic modelling (Chen et al., 2011; Malczewski, 2000). By obtaining the summation of the product of the relative importance weight (percentage of influence) of each criterion with its standard suitability score, a suitability index was determined (Eq. 3):

$$\mathrm{SI} = \sum w_i s_i \qquad \text{(Equation 3)}$$

where SI is the suitability index, *wi* corresponds to the relative importance of criterion *i* and *si* is the standardized suitability score of criterion i.

3.3.1.5. Analysis of current and future situation

In the study area, a total of 38 dams/reservoirs were abandoned, 37 are in use, and 15 are in the process of being built (ARAZAMBEZE, 2020). The infrastructures' georreferenced points were overlaid with the suitability map to check the coincidence level between these data sources providing an outlook of the water infrastructure in the region.

3.4. Results

3.4.1. Suitability criteria and reclassification

The nine criteria were reclassified using the suitability level presented in Table 6. This process resulted in nine maps presented in Fig. 16.

Table 6 -Site selection criteria used and level of suitability

	Suitability Level				
Criteria	Highly unsuitable	Not suitable	Modestly suitable	Suitable	Highly suitable
Elevation (m)	715-1545	493-715	361-493	214-361	0-214
Slope (º)	23,5-68,6	14,4-23.4	8,2-14.3	4,1-8.1	0-4
Soil	Arenosol, Calcaric Cambis, Ferric	Calcic Vertisol, Eutric Leptsol,	Stagnic or Hapl, Ferratic Arenosol, Chromic Luvisol	Mollic Fluvisol, Gleysol	Eutric fluvisol, Fluvisol

	Lixisol, Rhodic Ferralso				
Stream density	0-0,18	0,18-0,30	0,30-0,39	0,39-0,49	0,49-0,75
Lineaments (m)	0-100	-	-	-	100- 70225
Distance to Villages (km)	0-1	> 64,4	34,01- 64,4	24,1- 34,0	1-24,1
Land Use Land Cover	Evergreen forest, Bare Areas, Artificial water bodies	Grassland, Shrub lands, deciduous forest, Thickets	Closed to open forest with shift cultivation, Regularly Flooded shrub lands	Open forest, Aquatic/Regularly flooded	Cultivated area, Natural water bodies, shifting cultivation to open forest
Rainfall (mm)	599,1- 672,0	672,0- 751,3	751,3- 850,4	850,4- 964,7	964- 1107,9
Distance to Roads (km)	42,3-65,4	28,2-42,3	16,6- 28,2	1-16,6	0 -1

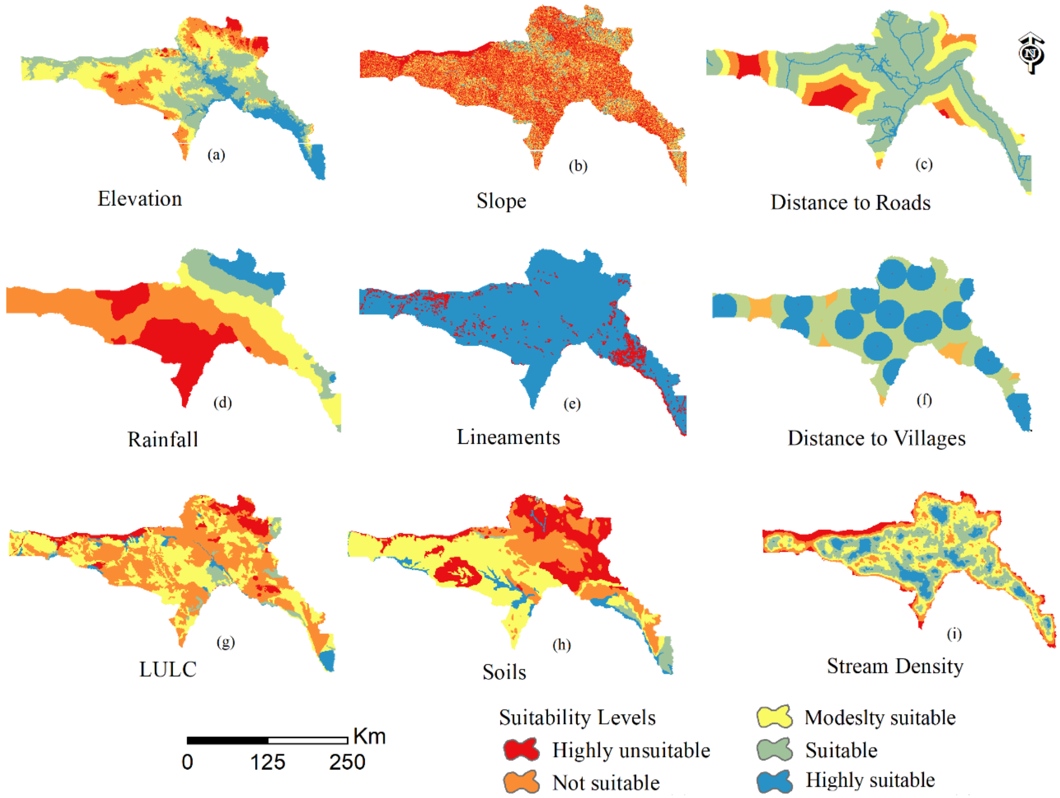

Figure 16-Standardized criteria for small dam/reservoir site selection

A low elevation was considered suitable for dam/reservoir siting since it enables the accumulation of precipitated water. Groundwater is also higher at a lower elevation (Fig. 15a). The slope ranged up to 68,9 degrees. The best locations were the ones with gentle slopes, i.e. areas up to 8,1% slope (Fig. 16b). The range of distance to roads for the study area was from 0 to 65.4 km. Areas within 0 to 1 km were assigned as “Highly suitable” and larger distances were considered from “Suitable” to “Highly unsuitable” (Fig. 16c). A high priority for siting dam/reservoir was given to locations with precipitation ranging from 964 mm to 1107,9mm (Fig. 16d). Regarding the lineaments, and because these geological structures can obstruct the normal stream-flow and cause the water reserves to collapse, the areas with or close to lineaments should be excluded from consideration to site a dam/reservoir (Noori et al., 2019). For the study area, the more distant a lineament is, the better the location for the dam/reservoir is (Fig. 16e). The proximity of the dams relative to residential areas can facilitate the task of finding a skilled workforce for the construction and maintenance work of the dam/reservoir itself, as well as making the transfer of water less expensive for rural populations (Emamgholi et al., 2015; Safavian & Amani, 2015). In this study, the areas closer to the village were classified as the most suitable (Fig. 16f). The increase in vegetation density results in an increase in the loss of interception, retention and infiltration rates, resulting in decreased flow volume. In turn, cultivated fields are suitable for certain types of rainwater harvesting technologies, while the riparian vegetation is not adequate (Mbilinyi et al., 2014). In this study, the most suitable LULC considered were the cultivated areas, natural water bodies, and areas shifting cultivation to open forest (Fig. 16g). The most suitable soils for dam/reservoir site locations should have a higher capacity for water retention (Adham et al., 2017). For the study area *Mollic fluvisol* and *Gleysol eutric fluvisol* were considered the most suitable because of their low permeability and higher water-holding ability (Othman et al., 2020) (Fig. 16h). For the stream density factor, a high priority was given to the locations where there was a high drainage density (0,79-0,75/km^2) when compared to areas of low drainage (Fig. 16i).

3.4.2. Pairwise comparison of criteria

Based on the local experts and decision makers' opinion, a matrix comparison with weight for all criteria was produced and then normalized (Table 7). Stream density was the most important factor (31%). Both distances to villages and roads were considered the least important factors (2%). We found a λ_{max}= 10.14, n=9, CI = 0.1425 and a CR of 0.098. Since the CR obtained was less than 0.1, the judgments of the experts were considered consistent (T. L. Saaty, 2008).

Table 7- Normalized pairwise comparison

Criteria	1	2	3	4	5	6	7	8	9	Weight
1	0.05	0.05	0.04	0.07	0.13	0.14	0.05	0.13	0	8%
2	0.05	0.05	0.05	0.07	0.13	0.1	0.05	0.13	0	7%
3	0.39	0.36	0.33	0.5	0.3	0.16	0.29	0.17	0.3	31%
4	0.05	0.05	0.05	0.07	0.17	0.12	0.1	0.09	0.2	10%
5	0.02	0.02	0.05	0.02	0.04	0.14	0.07	0.09	0.1	6%
6	0.01	0.01	0.04	0.01	0.01	0.02	0.03	0.02	0	2%
7	0.29	0.31	0.33	0.21	0.17	0.16	0.29	0.17	0.3	24%
8	0.01	0.01	0.04	0.01	0.01	0.02	0.03	0.02	0	2%
9	0.15	0.15	0.08	0.04	0.04	0.16	0.1	0.17	0.1	11%

(1: Slope; 2: Elevation; 3: Stream Density; 4: Land Use Land Cover; 5: Soil; 6: Distance to Roads; 7: Rainfall; 8: Distance to Villages; 9: Lineaments)

3.4.3. Suitability map

A suitability map for the dam/reservoir in the semi-arid zone of the Tete province was produced together with a histogram showing area and percentage for the different categories of suitability (Fig. 17). Although five classes of suitability were predefined, the results of the weighted overlay of the criteria revealed only three levels of suitability: “Not suitable”, “Modestly suitable” and “Suitable”. The suitability classes “Highly unsuitable” and “Highly suitable” were not found.

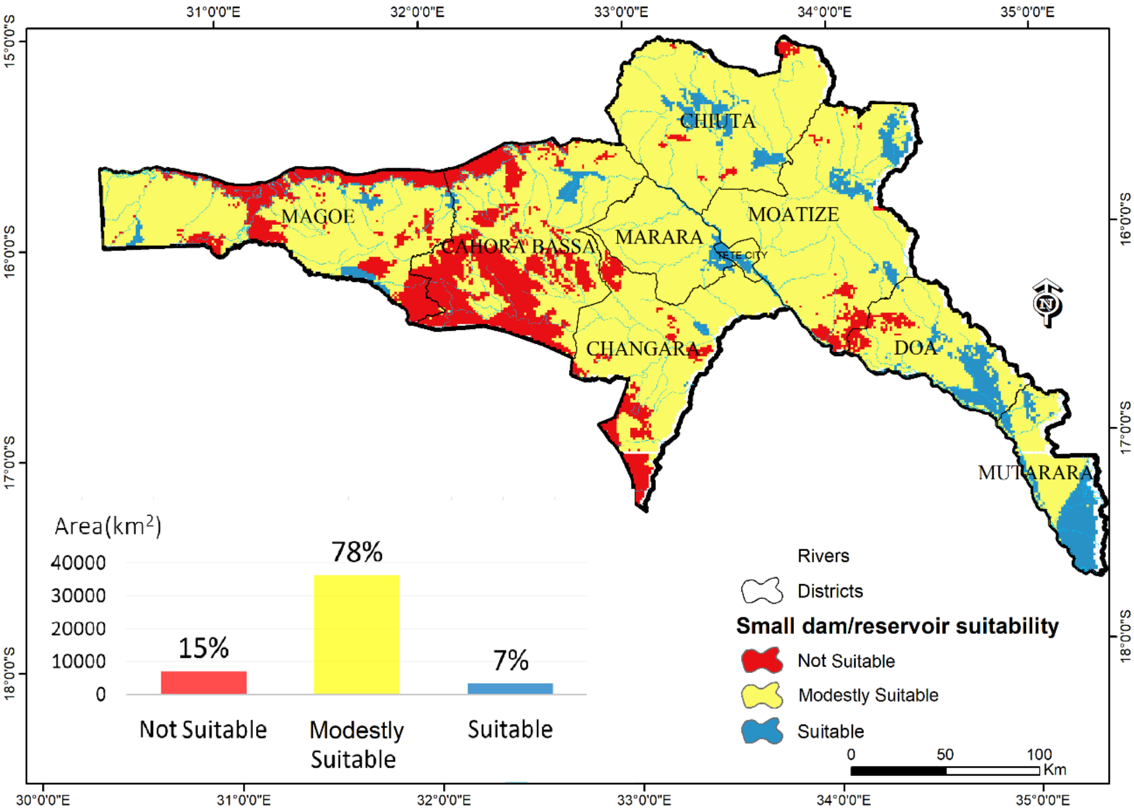

Figure 17-Small dam/reservoirs suitability categories for the study area

The “Modestly suitable” class occupies most of the study area (78%). The “Not suitable” class is predominant in the western zone of the study area, covering about 15% of the region, with emphasis on the districts of Cahora Bassa, Magoe and Changara, most likely due to reduced levels of rainfall and predominance of a drainage network with very low water flow. It is also possible to observe that Tete City districts, Marara and Mutarara contain only “Modestly suitable” and “Suitable” classes. The “Suitable” class only occupies 7% of the region. The individual analysis of the districts shows that Mutara, Doa, Moatize, Magoe and Cahora-Bassa are the districts with the highest coverage of suitable areas, in contrast to the districts of Marara, Changara and Tete city that have a lower coverage in this class. The comparative analysis by district reveals that although all districts have most of their area classified as “Modestly suitable”, the districts of Moatize, Magoe and Chiuta are the ones with the largest proportional area in this class (Fig. 18).

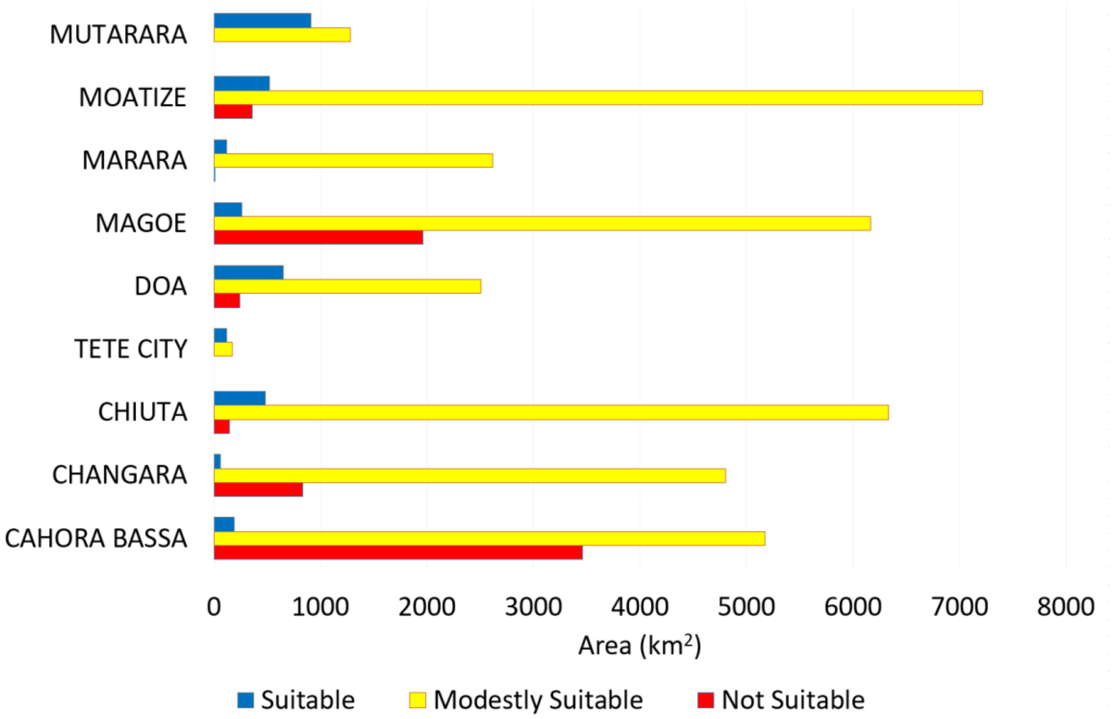

Figure 18- Level of suitability per district

3.4.4. Analysis of current and future situation

Recent data provided by AraZambeze (ARAZAMBEZE, 2020) indicates that the study area has 38 abandoned dams/reservoirs built with concrete and mortar stone, spatially distributed by the districts of Changara (15), Marara (11), Chiuta (4), Cahora-Bassa (3), Magoe (2), Moatize (2) and Doa (1). The spatial overlay of the abandoned dams and the streams order layers over the suitability level map shows that 35 out of the 38 abandoned dams were in the areas considered as modestly suitable, two dams were in not suitable areas, and only one abandoned dam was in a suitable area. All overlapping points coincide with areas with a stream order of less than 5, i.e., a very low runoff (Fig. 19).

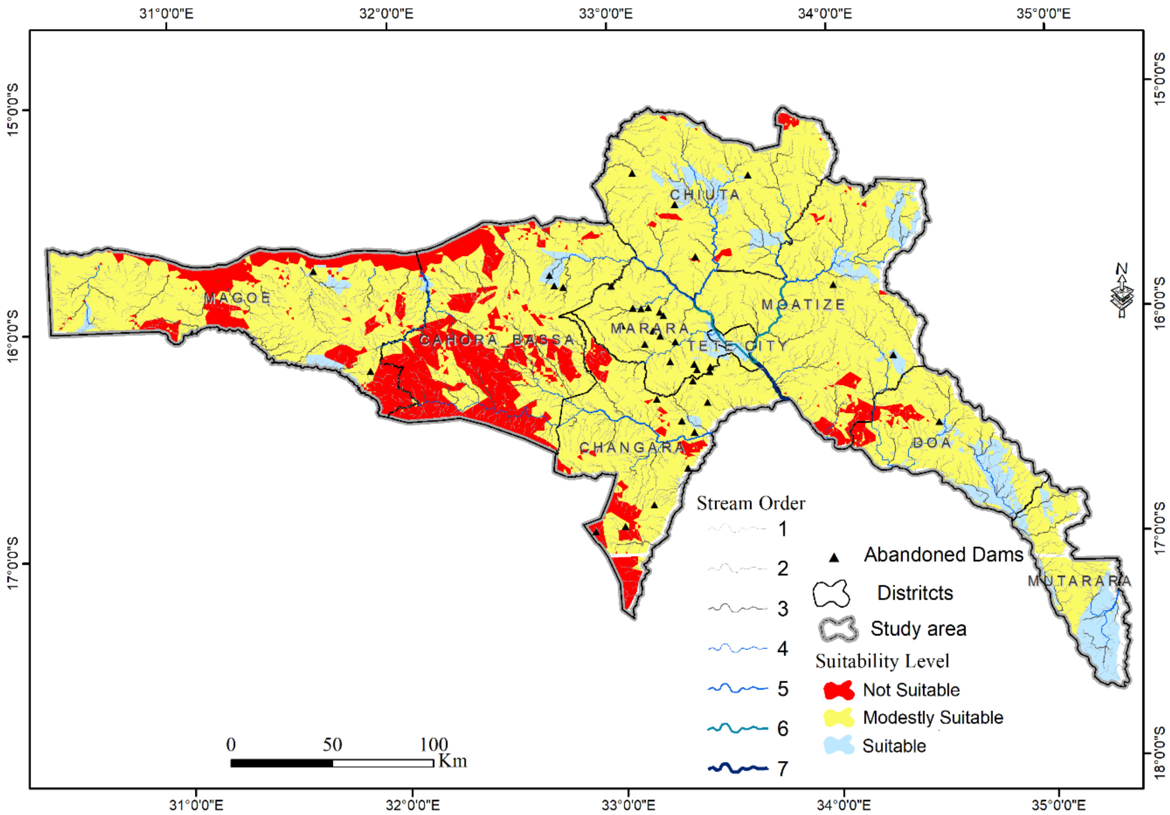

Figure 19-Abandoned dams/reservoirs overlaid with suitability map and streams

Currently, the region has 37 dams in operation located in the districts of Changara (19), Marara (7), Magoe (5), Cahora Bassa (4), Chiuta (1), and Moatize (1). As shown in Fig. 19, Changara and Marara districts, in the central area of the study area, have the largest number of dams (70.2%), whereas in the eastern districts Doa and Mutarara there is no operational dam. It is also noted that of 37 dams/reservoirs in operation, 78% overlap with the modestly suitable zones, 16.2% are in suitable areas and 5.4% are in not suitable areas. Most of these dams/reservoirs are found in rivers with little flow (stream order less than 5). To increase the number of dams/reservoirs to improve water availability to local communities in the dry season, different governmental entities and NGOs have financed the construction of new dams in the study area. Presently, 15 irrigation dams are under construction, located in the districts of Changara (4), Cahora Bassa (3), Moatize (3), Chiuta (2), Doa (1), Magoe (1), Marara (1). The overlay of these dams with the suitability map show that three dams are in areas considered "Suitable", 11 are in "Modestly suitable" areas and only one dam is in a "Not suitable" zone. Only two dams will be built in a stream order greater than 4 (Fig. 20).

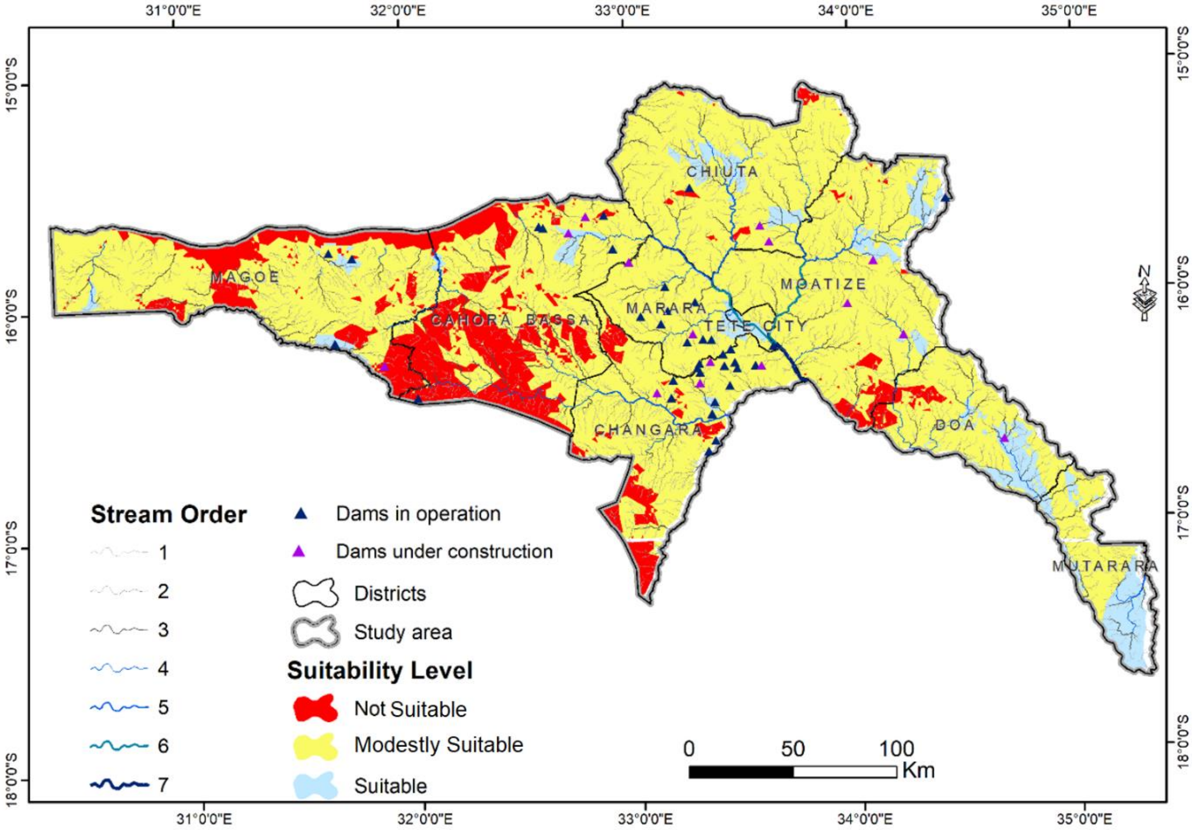

Figure 20-Geographic location of dams in operation and under construction

3.5. Discussion

3.5.1. Main findings and contribution

This paper contributes with a case study for locating the best places for building small dams/reservoirs in a semi-arid region of Mozambique using a GIS-based MCE approach with an AHP. We found that the stream density (31%), rainfall (24%), and lineaments (11%) were the most critical factors in determining the location of these infrastructures according to local expert knowledge. These factors have also been identified in previous studies as the most important ones (Al-Ruzouq, Shanableh, Yilmaz, et al., 2019; Elbeih, 2015). The study also compared the resulting suitability map with current and abandoned dams/reservoirs. This analysis showed that most of the study area falls inside modestly suitable areas (78%), 15% are in not suitable areas, and only 7% of the area is suitable for dam/reservoir construction confirming that in this area the rainfall regime is very low and with severe drought. According to the interviewed experts from AraZambeze, the lack of water in most of the year, silting, rupture, and erosion are the main causes of these dams' abandonment. The overlay of the layers of the dams/reservoirs that were abandoned (92%), operational (78%), and planned (or under construction) (73%) with the suitability map shows that most of these are in modestly suitable areas. This finding suggests that the decision to construct dams/reservoirs may not have considered the most critical suitability factors identified in this study. Since most of the dams/reservoirs still in operation are also in modestly suitable areas, the suitability criteria used may not fully explain whether these infrastructures are still in operation. It may be possible that the low suitability of a site may have contributed to the abandonment. The full understanding of finding out why so many dams/reservoirs failed seems important before building new ones and requires further analysis with more data and/or additional criteria.

3.5.2. Limitations and future developments

The results need to be interpreted with caution since there are limitations that should be considered in future developments of this study. For instance, the MCE modeling approach followed used WLC, which is an additive model that should, ideally, only use independent criteria (Karlsson et al., 2017). Otherwise, some of the factors used may be correlated, resulting in double-counting (Karlsson et al., 2017). However, as Malczewski (2000) pointed out, the requirements of decomposability and non-redundancy are difficult to justify in spatial decision problems. Future versions of this study should incorporate a strategy to avoid redundancy, such as the factor interaction method (A. et al., 2001).

Another limitation was the lack of a sensitivity analysis. Despite not being so commonly used in suitability analysis (Delgado & Sendra, 2004), a sensitivity analysis was not implemented. We could have varied the weights of the criteria to test if these significantly changed the results obtained. However, in this study, we wanted to incorporate the knowledge of credible local experts who have unique technical and local knowledge about the study area; three of them work for the Regional Water Administration and one has worked as a hydraulic engineer in an infrastructure building international company operating in Mozambique. Since AHP judgments were considered consistent, and the suitability model's results were validated by the abandoned dams/reservoirs, this option was not further explored.

The number of experts who participated in this study is low as in other previous studies with AHP (Alemdar et al., 2020; Dash & Sar, 2020; Peterson et al., 1994). Although, it would have been desirable to have more experts to possibly bring more relevant knowledge for the decision process, we had to work with the ones we could find for this study area in Mozambique. Nevertheless, a variability and confidence analysis regarding experts' level of knowledge about each criterion should be envisaged in future versions of this study to bring more credibility to the results (Campagne et al., 2017; Elliott et al., 2020). The dams/reservoirs' location would also benefit from a participatory process with stakeholders (Luijten et al., 2003; Roozbahani et al., 2020). Thus, for the process to be considered community property, it is recommended to conduct fieldwork for community consultation to assess the population's point of view regarding the construction of the dams/reservoirs in the proposed locations. Local communities and other stakeholders' involvement in water projects is crucial as it brings transparency, acceptability, support, and ensures the sustainability of the process (Dungumaro & Madulu, 2003). This element will prevent, for instance, land-use conflicts and will involve populations in the resolution of possible problems, such as erosion, siltation, and others. Future works aiming to improve results' quality and reliability should consider participatory events with all relevant stakeholders.

Aspects, such as local knowledge and the ability to maintain the dam/reservoir or access to better alternative water sources could also cause dam/reservoir failure. A more structured in-depth research using the same suitability criteria to determine the exact reasons for abandoning dams/reservoirs could have been done. This action would enable verifying if the criteria used for the suitability analysis were well chosen. Unfortunately, we did not have data to check precisely why each dam/reservoir failed. We only had information about their location and operational status. To pinpoint why each specific dam failed would involve field work which we could not do due to lack of resources. However, future versions of this work should include this aspect since it would validate the results more consistently.

Another possible improvement for this study is data. For instance, we could use locally measured rainfall data instead of interpolated global data (Fick & Hijmans, 2017), which is known to have substantial discrepancies (Faye et al., 2014). Although we tried to use the best possible data, future versions of the suitability model will benefit from more accurate datasets when these are made available.

3.5.3. Conclusions

Identifying suitable areas for building small dams/reservoirs is essential for the study area, a semi-arid region with important water deficits. The approach followed in this study based on GIS-based MCE together with an AHP enabled us to obtain information about the relevant variables (i.e., slope, elevation, rainfall, stream density, lineaments, soil, land-use land cover and two socioeconomic factors, distance to roads and distance to villages) to create a small dam/reservoir suitability map for the region of Tete, Mozambique. Results show that most of the currently operating and planned small dams/reservoirs are located in modestly suitable areas. This means that the main location factors for building a dam are not being considered, reinforcing the need to use a spatial MCE approach. This information raises concerns about the future effectiveness of these infrastructures and should be carefully analyzed by planners to better address the population's water needs in the region. The methodology is flexible enough to easily consider additional criteria, experts/stakeholders, and up-to-date data in the process of deciding where to locate these infrastructures in semi-arid regions or any other locations facing water scarcity problems.

Chapter 4: Conclusion

Geographic information systems as analytical and decision-making tools demonstrated in this study to have an incomparable power to examine essential public services. The study aimed to analyse spatially the essentials public services in Mozambique using travel time accessibility analysis and site selection multi criteria methods. Consequently, as a result of the study, the two objectives were accomplished:

- Measure the geographic accessibility to the Healthcare Centers in Mozambique

The issue of distance and time as barriers to healthcare services has not been well documented and there are no accessibility maps showing how far or close the communities are to the health facilities in Mozambique. This study aimed to fill this knowledge gap by measuring geographical accessibility to HC facilities in Mozambique, calculating the spatial coverage of the existing primary HC facility network using the scenarios of driving and walking travel time and subsequentely estimate the number of people within served and underserved area. Resulted maps of travel time to healthcare unities for both scenarios of travel ,provides a valuable resource for Mozambican policymakers tasked with allocating personnel and resources to improve population health acessibility.

- Identify the most suitable dam/reservoir sites for the semi-arid zone of the Tete Province, Mozambique

The situation of water scarcity in semi-arid regions in Mozambique is currently alarming and, therefore, requires technical adaptation of water conservation. To mitigate this situation, the Mozambican government has defined as strategic and priority objectives the rehabilitation and construction of some small dams / reservoirs, making it necessary to identify the best locations for the implementation of these infrastructures.

In addition, the research aims to respond to the goals of the SDGs and the Community Water Development Protocol, which suggests an action plan for mitigating drought and creating infrastructure to increase storage capacity and reduce water loss particularly in arid and semi-arid areas. This research identified the most suitable locations for the location of small dams / reservoirs for the semi-arid zone of Tete in Mozambique.

4.1. Summary of the results

The results of this research show that in terms of geographical accessibility, walking time is the most problematic and worrying scenario because the majority of the Mozambican population (90.2%) is located or need 60 minutes or more to reach an HC, contrary to the of driving time scenario where only 6% of population is located on underserved area. In administrative terms Tete, Cabo Delgado and Gaza with about 93% are the provinces with the most underserved areas.

The findings demonstrated that the level of accessibility is similar to those faced by many African countries and completely opposite to those of developed countries where people can access hospital care in less time.

Relatively to the site location for dam/reservoir for the semi-arid region of Tete, the study created three main categories of suitability "Not suitable" (15% of total area), "Modestly suitable" (78%), and "Suitable" (7%). It appears that 92% of abandoned small dams/reservoirs were in areas classified as "Modestly suitable" confirming the robustness of our model. We also found that most of the dams/reservoirs currently operating (78%) and planned (73%) are in modestly suitable areas.

The spatial overlay of the abandoned dams and the streams order layers over the suitability level map shows that 35 out of the 38 abandoned dams were in the areas considered as modestly suitable, two dams were in not suitable areas, and only one abandoned dam was in a suitable area. It was observed that all abandoned dam's area located on a stream order with a very low runoff.

4.2. Main contributions

Strengthening health systems and ensuring increasing equitable access to health services, and expanding the coverage are a top strategic priority for the country. This research helped to fill the gap in the lack of accessibility maps for health services in Mozambique and let us know the served and underserved area of primary health care services.This study highlights critical areas in Mozambique in which HC are lacking when assessed by walking and driving travel time distance. The mapped outputs may have policy implications and can be used for future decision-making processes and analysis. The results are locally highly significant and could be used for advocacy and presentations to donor partners and government, to improve roads and the number of HC in underserved areas.

In methodological terms the research has contributed to the knowledge first for studying the accessibility analysis considering the road network avoiding Euclidean distances, as recommended by WHO (Munoz & Källestål, 2012); and second, for countering the trend of many previous studies that analyzed the geographical accessibility to health centers only from a distance point of view and did not consider the travel time factor.

The dam/reservoir site study provided the first dam/reservoir suitability mapping for a semi-arid region in Mozambique. This aspect is crucial since one of the strategic and priority objectives of the Mozambican government is to reduce the vulnerability of rural communities to climate risks and natural disasters through the rehabilitation and construction of 80 small dams/reservoirs to support irrigation for small producers and increase production in drought agricultural areas and improve food security. The novelty of the paper is not methodological since MCE and AHP have been applied widely before and in many different contexts. The added value of the paper is the study area which never has been covered before. Water scarcity is a huge problem in the studied region as well as in other regions of the world which can benefit from the methodology described in this paper. We found no published studies for Mozambique and our expert-based knowledge about the study area allowed us to show based on data that many of the existing dams were not well planned. We believe this paper can revert this situation in the future and contribute with relevant information to the Southern African Development Community water protocol and international donors.

4.3. Limitations and future research

4.3.1. Limitations

The main limitations in the geographic accessibility to the healthcare centers study (chaper 2) was the lack or difficulty in obtaining georeferenced and updated data to use in modeling. Another limitation is the fact that the research focuses exclusively on the location of geographically fixed facilities and ignores the potential use of mobile or temporary clinics for providing healthcare,especially in remote areas.

Finally, although we used realistic travel time in our analysis, this study estimated the normal speed of the individual, without specifying his age, gender or any physical limitation that conditions his mobility.

For dam/reservoirs site location study (chapter 3) the main limitation is the lack of concise information for the resason of abandomed dams.Unfortunately, we do not have data to check why exactly each dam failed. We only have information about if they are active or not. To find about why each specific dam failed would involve field work which we cannot do due to lack of resources.

4.3.2. Future research

For the geographic accessibility to the healthcare centers study, it would be useful to consider the elements of age, gender and other limitation factors for calculating travel times in the future studies. In addition, it would be important to incorporate travel cost to identify areas where costs act as obstacles for the health accessibility. Since the concept of accessibility encompasses other dimensions and is not restricted to geographical dimensions future studies should be focused on other dimension such as health care availability, financial accessibility and acceptability.
On other hand, for dam/reservoirs site location study, the full understanding of finding out why so many dams/reservoirs failed seems important before building new ones and requires further analysis with more data and/or additional criteria.

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